DRAFT STAFF REPORT

Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline

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This report assesses the vulnerability of San Francisco Bay and its shoreline to the impacts of climate change, identifies information needs for future vulnerability assessments, and suggests near-term and long-term strategies to address climate change impacts. Where feasible, those strategies are incorporated into recommended findings and policy revisions to the *San Francisco Bay Plan*. The preparation of this report was supported by a grant from the National Oceanographic Atmospheric Administration, Office of Coastal Resource Management.

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Executive Summary

San Francisco Bay is a national treasure that helps sustain the economy of the western United States, provides wonderful opportunities for recreation, nourishes fish and wildlife, provides unparalleled scenic splendor, and in countless other ways enriches our lives. The Bay is the principal visual icon of our region, whether seen when traveling by car or rail along the shoreline, landing at an airport, strolling along the shoreline, or watching the fog stream in on a summer's day. Managing the threats to the Bay and shoreline development from sea level rise will be one of the defining challenges we face in the 21^{st} century.

A richly varied composite of urbanization and nature exists in and around San Francisco Bay. Urban waterfronts, critical habitat areas, industrial areas and residential neighborhoods coexist within walking distance of each other. Overlaid on these shoreline places is a vital system of public infrastructure, including freeways, seaports, railroads and airports, which knit the shoreline communities together and connect them to the rest of the region, California and the world. This tapestry helps make the beauty of the Bay Area world-renowned and underpins its economy, the health of its natural systems and the quality of life of its inhabitants. Over the past 150 years, the productive use of the Bay's shoreline has become the cornerstone of the region's prosperity and forged an inseparable bond between the people of the Bay Area and the Bay itself.

The nine-county San Francisco Bay Area is home to approximately seven million people making the Bay one of the world's most urbanized estuaries. Climate change has the potential to dramatically impact the economy, environment and quality of life in the Bay Area. Changes in personal behavior, institutional actions, and government policies are needed to reduce greenhouse gas emissions, moderate temperature increases attributed to global warming, and mitigate climate change. To some extent, the choice to alter lifestyles and institutional priorities now will reduce the degree to which the world must adapt to the effects of climate change. However, no matter how effectively the world reduces greenhouse gas emissions, oceans have already warmed, sea levels are already rising at accelerated rates, and are likely to accelerate further. Therefore, while mitigating climate change by reducing greenhouse gas emissions is essential, adapting to climate change and its impacts is unavoidable.

Local governments and land management agencies already face challenging issues, such as dealing with competing land uses, ensuring that adequate shoreline areas remain available for water-dependent uses, upgrading aged infrastructure, reducing traffic congestion, protecting habitat and water quality, maintaining flood protection, and providing public shoreline access. Shoreline vulnerability assessments can help government agencies and the public understand how existing planning and management challenges will be exacerbated by climate change and assist in developing strategies for dealing with these challenges.

The Vulnerability Assessment

Two sea level rise projections were selected as the basis for the vulnerability assessment in this report: a 16-inch (40 cm) sea level rise by mid-century and a 55-inch (140 cm) rise in sea level by the end of the century. When BCDC initiated its effort to amend the Bay Plan to address climate change in 2009, the State of California was still in the process of formulating statewide policy direction for adapting to sea level rise. In 2010 the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) developed a Sea Level Rise Interim Guidance document that advises the use of projections (relative to sea level in 2000) for the state that range from 10 to 17 inches by 2050, 17 to 32 inches by 2070, and 31 to 69 inches at the end of the century (based on work by Vermeer and Ramstorf, 2009). This document was endorsed by a resolution of the California Ocean Protection Council in 2011. The projections used in BCDC's report fall within the ranges suggested by the CO-CAT's Sea Level Rise Interim Guidance document. The CO-CAT has recognized that it may not be appropriate to set definitive sea level rise projections, and, based on a variety of factors, state agencies may use different sea level rise projections. Although the CO-CAT values are generally recognized as the best science-based sea level rise projections for California, scientific uncertainty remains regarding the pace and amount of sea level rise. Moreover, melting of the Greenland and Antarctic ice sheets may not be reflected well in current sea level rise projections. The interim guidance will be updated consistent with the National Academy of Sciences sea level rise assessment report, expected in 2012, and other forthcoming studies.

Using the two sea level rise projections, the vulnerability assessment focused on three planning areas or systems: shoreline development, the Bay ecosystem, and governance. Key sectors within each system, such as land uses or subregions of the Bay, were used to assess their sensitivity, adaptive capacity and, ultimately, their vulnerability.

1. Shoreline Development

Residents, businesses and entire industries that currently thrive on the shoreline will be at risk of flooding by the middle of the century, and probably earlier, if nothing is done to protect, elevate or relocate them. A 16-inch rise (relative to sea level in 2000) would potentially expose

281 square miles of Bay shoreline to flooding, and a 55-inch rise would potentially expose 333 square miles to flooding. If no adaptation measures were taken, a 55-inch rise in sea level would place an estimated 270,000 people in the Bay Area at risk from flooding, 98 percent more than are currently at risk. The economic value of Bay Area shoreline development (buildings and their contents) at risk from a 55-inch rise in sea level is estimated at $62 billion—two-thirds of all the estimated value of development vulnerable to sea level rise along California's entire coastline. In those areas where lives and property are not directly vulnerable, the secondary and cumulative impacts of sea level rise will affect public health, economic security and quality of life. Additionally, changes in climate may cause increased storm activity, which in combination with higher sea level, may cause even greater flooding. It is expected that extreme storm events will cause most of the shoreline damage from flooding.

Shoreline development located in an area potentially exposed to a 100-year high water event in 2000 could be potentially exposed to regular tidal inundation by mid-century, not taking existing and planned shoreline protection into account. Approximately half of that development is residential, totaling 103 square miles. Over 128 square miles of residential development is at risk of flooding by the end of the century. Where residents are not directly at risk of flooding, access to important services such as commercial centers, health care, and schools would likely be impeded by flooding of the service centers or the transportation infrastructure that links them. Rising sea levels could impact the delivery of petroleum products, electricity, and drinking water to Bay Area residents and businesses. Dealing with this range of impacts will be more difficult for low-income residents because they have less financial flexibility and fewer resources to pursue alternative housing and transportation.

Populations may suffer if wastewater treatment is compromised by inundation from rising sea levels, given that a number of treatment plants discharge to the Bay. Impaired water quality and higher temperatures can result in algal blooms and a higher potential for the spread of water-born disease vectors.

Large commercial and industrial areas are at risk of flooding, especially in San Francisco, Silicon Valley, and Oakland. Approximately 72 percent of each of the San Francisco and Oakland Airports is at risk from a 16-inch sea level rise and about 93 percent of each is at risk from a 55-inch sea level rise, which could disrupt as many as 30 million airline passengers annually and approximately one million metric tons of cargo. Flooding of highway segments in the regional transportation network could disrupt the movement of goods from ports, which handled approximately 25 million metric tons of cargo in 2007-2008. Other water-related industries would be similarly affected. Flooding of the rail system would be particularly serious, because multiple carriers share a single line in most locations around the Bay.

Waterfront parks and public access provide opportunities to enjoy the Bay and remind us of its place in the region. There are 36 square miles of waterfront parks, of which 14 percent are at risk under the lower scenario and 18 percent at risk under the higher scenario. Fifty-seven percent of the public access required by BCDC is at risk under the low scenario and 87 percent at risk under the high scenario. The decline of waterfront recreational opportunities would impact the quality of life in the Bay Area.

To address widespread flooding from storm activity and sea level rise, risk assessments and adaptive strategies will be needed. Risk assessments should use the best available science-based projection for sea level rise at the end of the century and should identify all types of potential flooding, degrees of uncertainty, consequences of defense failure, and risks to existing habitat from proposed flood protection devices. Approaches for ensuring public safety in developed vulnerable shoreline areas through adaptive management include, but are not limited to: (1) protecting existing and planned appropriate infill development; (2) accommodating flooding by building or renovating structures or infrastructure systems that are resilient or adaptable over time; (3) discouraging permanent new development when adaptive management strategies cannot protect public safety; (4) allowing only new uses that can be removed or phased out if adaptive management strategies are not available as inundation threats increase; and (5) where feasible and appropriate, removing existing development where public safety cannot otherwise be ensured. Determining the appropriate approach and financing structure requires weighing various policies and is best done through a collaborative approach that directly involves the affected communities and other governmental agencies with authority or jurisdiction. Some adaptive management strategies may require action and financing on the regional or sub-regional level across jurisdictions.

Where shoreline protection is necessary to protect development, it should be constructed to provide protection for a 100-year flood that takes future sea level rise into account. Shoreline protection can be structural, natural, or a combination of both. Choosing the appropriate form of shoreline protection—one that both protects public safety and minimizes ecosystem impacts—is critically important. In the long-term, the region needs to engage in an open and vigorous public dialogue to make the difficult decisions about where and how existing development should be protected and infill development encouraged, where new development should or should not be permitted, and where existing development should eventually be removed to allow the Bay to migrate inland.

2. The Bay

The numerous plants and animals that inhabit the Bay provide many benefits to humans. For example, tidal wetlands provide critical flood protection, improve water quality, and sequester carbon. The brackish marshes in the North Bay and Suisun Marsh contain a great diversity of species and provide an important resting place along the Pacific Flyway. The impacts of climate change are expected to substantially alter the Bay ecosystem by inundating or eroding wetlands and transitional habitats, altering species composition, changing freshwater inflow, and impairing water quality. Changes in salinity from reduced freshwater inflow may adversely affect fish, wildlife and other aquatic organisms in intertidal and subtidal habitats. The highly developed Bay shoreline constrains the ability of tidal marshes to migrate landward, while the declining sediment supply in the Bay reduces the ability of tidal marshes to grow upward as sea level rises.

The Bay will continue to evolve in response to the climatic forces that enabled it to come into being. Historic modification of the ecosystem, through filling, diking, and building on the shoreline and reducing freshwater inflow, as well as ongoing stressors such as pollution and invasive species, have resulted in the decline of many native species and increased the vulnerability of surrounding communities to damaging floods. Substantial progress has been made in restoring the Bay ecosystem by returning diked areas to tidal action and reducing pollution, while efforts to increase freshwater inflow have been less successful. Future efforts to restore the Bay ecosystem can benefit from careful design that accounts for the known processes affecting formation of habitats in the Bay, the constraints imposed by existing stressors, and the future vulnerabilities associated with climate change.

Key questions that resource managers must address regarding climate change include: identifying opportunities for tidal wetlands and tidal flats to migrate landward, managing and maintaining adequate volumes of sediment for marsh sedimentation, developing and planning for natural flood protection, and maintaining sufficient upland buffer areas around tidal wetlands. Furthermore, rare and valuable habitats, like beaches, should be high priority for restoration and conservation.

Developing effective strategies to protect tidal wetlands from sea level rise is extremely challenging because the projections of future sea level rise continually change. Since the 1980s, when widespread scientific concern about climate change and sea level rise emerged, projections for sea level rise have varied widely. This range of variation, based on different climate models and emission scenarios, creates a great deal of uncertainty for decision-makers; therefore, wetland protection strategies must be adaptable to changing conditions.

As the rate of sea level rise accelerates and the potential for shoreline flooding increases, the demand for new shoreline protection projects will likely increase. Most structural shoreline protection projects involve some fill, which can adversely affect the natural resources of the Bay. Structural shoreline protection can also cause erosion of tidal marshes and tidal flats, prevent wetland migration to accommodate sea level rise, and create a barrier to physical and visual public access to the Bay. Shoreline protection also has cumulative impacts. In some instances, it may be possible to combine habitat restoration, enhancement or protection with structural approaches to provide protection from flooding and control shoreline erosion, thereby minimizing the impacts of shoreline protection on natural resources.

Cumulative impacts of structural shoreline protection can have far reaching adverse impacts to the Bay ecosystem. Planning for sea level rise at a regional level can reduce those impacts and address difficult issues, such as the desire to provide shoreline protection for undeveloped shoreline areas.

3. Governance

The Bay Area faces a range of vulnerabilities in its systems of governance that reduce the region's ability to adapt to sea level rise and other climate change impacts on the Bay and shoreline. A look at the region's overall governance system suggests that existing challenges to regional planning caused by the patchwork of federal, state, regional and local government authorities in the Bay region will be exacerbated by climate change impacts.

BCDC faces governance vulnerabilities in its laws and policies. The Commission's jurisdiction on the shoreline is limited to 100 feet landward of the mean high tide line, and within this area, BCDC's authority is limited to requiring maximum feasible public access and consistency with designated priority land uses. The Commission's law is based on the principles of the public trust doctrine, which may move inland as sea level rises. Furthermore, because BCDC implements its authority on a permit-by-permit basis, the Commission is limited in its ability to address the cumulative impacts of individual shoreline protection projects. The existing framework of BCDC's laws and policies that focus on preventing the Bay from shrinking is an overarching constraint to the Commission's ability to effectively plan for and adapt to climate change impacts.

Local governments and other management agencies, especially in cities and counties, have broad authority over shoreline land use. However, they lack policy incentives, resources and regional guidance for addressing climate change impacts in land use planning. To address these gaps, local governments need information about Bay-related impacts of climate change that is region-specific and site-specific. The information should include a regional model that projects 50 and 100 years into the future. The projections should be developed through a public, inclusive process in order to be widely accepted and used throughout the region. The system most commonly used by local governments for analyzing information is GIS. However, local planners and resource managers can benefit from guidance documents, such as sample ordinances.

Lack of staff and adequate financial resources are the primary barriers to planning for impacts of climate change, both statewide and in the Bay Area. Any assistance to local governments and public management agencies must address this issue either by providing more staff and financial resources or by providing information that is easily integrated into existing operations, planning tools, guidance documents and planning processes (e.g., General Plan updates).

Adaptation Strategies

Adapting to climate change on the San Francisco Bay shoreline is critical to the region's economic stability, safety and public health. Flooding from sea level rise alone threatens the long-term viability of our neighborhoods, job centers, transportation, water and wastewater infrastructure, schools and fire stations and vital ecosystem services on which our quality of life and the regional and state economies depend.

To integrate rapidly advancing scientific knowledge about the impacts of climate change, adaptation planning for the Bay and shoreline must be a flexible and iterative process. Shoreline planning will be increasingly challenging as the line between uplands and Baylands becomes more dynamic, thereby requiring a creative planning approach that integrates both the natural and the built environment. An ecosystem-based, adaptive management approach would integrate the human component of ecosystems into ecosystem management by bringing stakeholders into decision-making processes, promoting interagency collaboration, and providing direction through those processes.

This report presents a framework for selecting adaptation strategies to address key vulnerabilities and risks at various scales and timeframes. In the near term, the Commission can require applicants to develop resilient designs and adaptation strategies when planning shoreline areas or designing larger shoreline projects within BCDC's limited jurisdiction. Ultimately, effective adaptation will require strategies that integrate climate mitigation and adaptation efforts regionally. The Commission can help facilitate a collaborative process to develop a regional strategy to deal effectively with sea level rise and other adaptation challenges in the Bay Area.

Proposed Bay Plan Amendment

Adaptation to climate change should be incorporated into the Bay Plan in the following manner:

1. Create a climate change policy section of the Bay Plan that addresses the following:
    a. Incorporating sea level rise projection ranges in project design and planning and using them in the permitting process;
    b. Developing a long-term strategy to address sea level rise and storm activity and other Bay-related impacts of climate change in a way that protects the shoreline and the Bay and allows for appropriate, well-planned development that responds to the impacts of climate change and future sea level rise;
    c. Working with the Joint Policy Committee (JPC) and other agencies to integrate mitigation and adaptation strategies at a regional scale, to coordinate the adaptation responses of multiple government agencies, to analyze and address social equity issues, and to support research that provides useful climate change information and tools;
    d. Providing recommendations and requirements to guide planning and permitting of development in areas vulnerable to sea level rise; and
    e. Including policies that promote wetland protection, creation, enhancement and migration.
2. Amend findings and policies on tidal marshes and tidal flats to ensure that buffer zones are incorporated into restoration projects where feasible and sediment issues related to sustaining tidal marshes are addressed.

3. Amend the policies on safety of fills by updating the findings and policies on sea level rise and moving some to the new climate change section of the Bay Plan.
4. Amend the policies on protection of the shoreline to address protection from future flooding.
5. Amend findings and policies on public access to ensure that public access is sited, designed and managed to avoid significant adverse impacts from sea level rise and to ensure long-term maintenance of public access areas through site-specific adaptive management strategies.

CHAPTER 1
Causes of Sea Level Rise

Greenhouse gas (GHG) emissions have already contributed to an increase in average global temperature and may trigger irreversible impacts from continued global warming. A rise in global temperature is expected to be accompanied by other climatic changes and impacts, such as increased frequency of temperature extremes; changes in precipitation patterns; reduced soil moisture content; melting of polar ice caps, land-based ice sheets and glaciers; ocean warming and consequent changes in sea level and water circulation. Detrimental impacts to ecosystems will likely affect public health and the economy. This chapter explains the causes of climate change, the United Nations Intergovernmental Panel on Climate Change (IPCC) scenarios, the California Climate Action Team's scenarios, and the Bay Area's contributions to and efforts to mitigate GHG emissions. It further explains the causes of sea level rise, increased storm activity, and sea level rise scenarios that should be used to minimize risks on the shoreline. Finally, this chapter describes the approach to the vulnerability assessment in Chapters 2-4 and discusses shoreline protection options.

The Greenhouse Effect and Global Warming

The "greenhouse effect" is a natural system that controls the Earth's temperature. Water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), residing in the Earth's atmosphere, absorb heat emitted from the Earth's surface and radiate heat back to the surface. The Earth's surface temperature would be about 61°F (34°C) colder than it is now without this natural heat trapping system (CAT 2006).

The Earth's climate is dynamic and constantly changing. However, recent observations and modeling indicate that the rate and magnitude of change occurring today is unprecedented for the most recent geologic period (the Quaternary period or last 2 million years). Ice core samples provide information about historic concentrations of GHGs and provide information about human contributions to global climate change. Concentrations of CO_2 in the samples correlate to recent observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. The IPCC reported in its Fourth Assessment Report (AR4) that the current observed global average temperature increase is about 0.36°F (0.2 °C) per decade (IPCC 2007).

There are both human and natural causes of climate change. Radiative forcing is a measure of how the balance of incoming and outgoing energy in the Earth-atmosphere system is influenced by factors that alter the climate system, such as changes in the amount of GHGs in the atmosphere, in solar radiation, and in land surface. Radiative forcing is studied to analyze how much various human and natural factors contribute to warming or cooling (IPCC 2007). The IPCC AR4 examined radiative forcing from human and natural factors and concluded that: (1) it is extremely unlikely that global climate change of the past 50 years can be explained without human contributions of GHGs; (2) carbon dioxide is the most important human contribution to greenhouse gases; and (3) the primary source of the increased CO_2 is from fossil fuel use with land-use change as another significant, but smaller contribution. There is a broad consensus in the scientific community that climate change is occurring and the release of GHGs caused by human activities is accelerating this change.

Emissions Scenarios. While scientists agree that the planet is warming, the amount and timing of this change is less certain and likely will remain so for some time. In order to predict future climate change, it is necessary to know how much GHGs will be produced in the future. It is difficult to predict future GHG emissions without knowing how global development will proceed. The IPCC addressed this uncertainty by developing future global development scenarios, which are included in a Special Report on Emissions Scenarios (SRES). For each scenario, the key activities that influence global development rates were altered to produce a range of future development patterns. Specific variables, such as population, economic growth, technological change, resource availability, and land-use changes were considered in order to quantify GHG emissions relative to each scenario (IPCC 2000). Four scenarios were developed to cover a wide range of variables: the A1 scenario breaks into four sub-scenarios, one of which (A1FI) has the highest emissions of all the scenarios; the A2 scenario also has high emissions; B1 has the lowest emissions; and B2 is a middle-range emissions scenario.

The SRES was published in 2000 and the scenarios continue to be widely used in assessments of future climate change. In AR4, a warming of about 0.36° F (0.2° C) per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols (small particles in the atmosphere that absorb and scatter radiation, such as smoke or dust) were kept constant at 2000 levels, a further warming of about 0.2°F (0.1°C) per decade would be expected (IPCC 2007). The projected global temperature increase at the end of the century in the range of SRES is between 3.2° F and 6.8° F (1.8° C and 3.8° C) (Table 1.1). Mitigating or reducing GHG emissions is critical to slow climate change, but mitigation will not stop changes that are already underway. Therefore, adapting to climate change is equally critical as mitigating climate change.

Table 1.1. Projected Global Average Surface Warming at the End of the Century

Scenario	Temperature Change (Degrees at 2090-2099 relative to 1980-1999)			
	Best Estimate		Likely Range	
	°F	°C	°F	°C
Constant year 2000 concentrations	1.1	0.6	0.5 – 1.6	0.3-0.9
B1	3.2	1.8	2.0 – 5.2	1.1 - 2.9
B2	4.3	2.4	2.5 – 6.8	1.4 – 3.8
A2	6.1	3.4	3.6 – 9.72	2.0 – 5.4
A1FI	6.8	3.8	4.3 – 11.5	2.4 – 6.4

Adapted from IPCC 2007.

The California Climate Action Team. While the IPCC assessments of climate change rely on global models, adapting to climate change requires an understanding of how climate change will impact specific regions so that planning can take place at the state and regional levels. The California Climate Action Team (CAT) relies on the IPCC emissions scenarios for assessing the primary impacts of climate change on a regional level, namely changes in the frequency and intensity of precipitation and temperature increases (Cayan et al. 2006 (a), Cayan et al. 2006 (b) and Cayan et al. 2009).

For its 2009 California climate change assessment, the CAT chose two IPCC scenarios to evaluate: A2 (a medium-high emissions scenario) and B1 (a low emissions scenario). Researchers used the A2 and B1 scenarios to run multiple global climate computer models and performed additional research to project specific climate changes in California (Cayan et al. 2009).

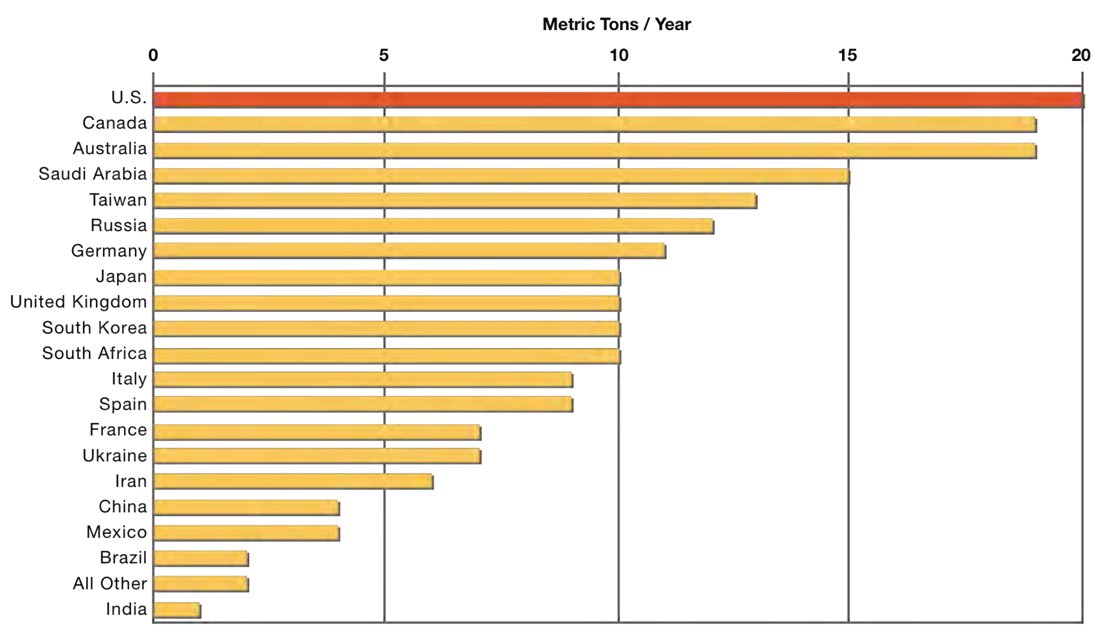
The CAT projects that temperatures will get higher in the inland areas of California than on the coast. Overall, the projected warming is consistent with IPCC projections: between 1.8°F and 5.4°F (1°C and 3°C) by mid century and between 3.6°F and 9°F (2°C and 5°C) by the end of the century (Cayan et al. 2009). Temperature increases in the lower range of warming are projected to be similar to the difference in average annual temperature between Monterey and Salinas. In the upper range of projected warming, the temperature difference would be closer to that between San Francisco and San Jose (Cayan et al. 2006 (a)).

The CAT findings regarding precipitation were similar to findings for the globe, with a tendency toward drier conditions at the end of the century (Cayan et al. 2009). Generally, even a small decline in precipitation can be problematic for California because demand for water for environmental, urban and agricultural purposes already exceeds supply. Furthermore, about one third of California's water currently falls as snow in the Sierra Nevada Mountains and much of the water stored in the Sierra snowpack and reservoirs is used in the Central Valley, the Bay Area and Southern California during the spring and summer. As temperatures rise, the snowpack will melt earlier and less precipitation will fall as snow, further hampering California's ability to store enough water and provide it to agricultural fields and growing populations. Changes in the amount and timing of fresh water that flows to the Bay from the Sierra Nevada watershed will directly affect the Bay ecosystem.

As an example of the scope of the impacts within one economic sector, California's $30 billion agriculture industry currently uses almost 80 percent of developed water in the state (DWR 2006). However, in addition to adverse impacts stemming from changes in the state's water management system, some of the state's most lucrative crops, such as wine grapes, fruits and nuts could falter under higher temperatures. Furthermore, high temperatures can stress dairy cows, severely hampering what is currently a $3 billion industry.

Figure 1.1 U.S. Contribution To Global CO_2 Emissions (per Capita)

Source: U.S. Energy Information Administration; Bay Area Air Quality Management District, 2007



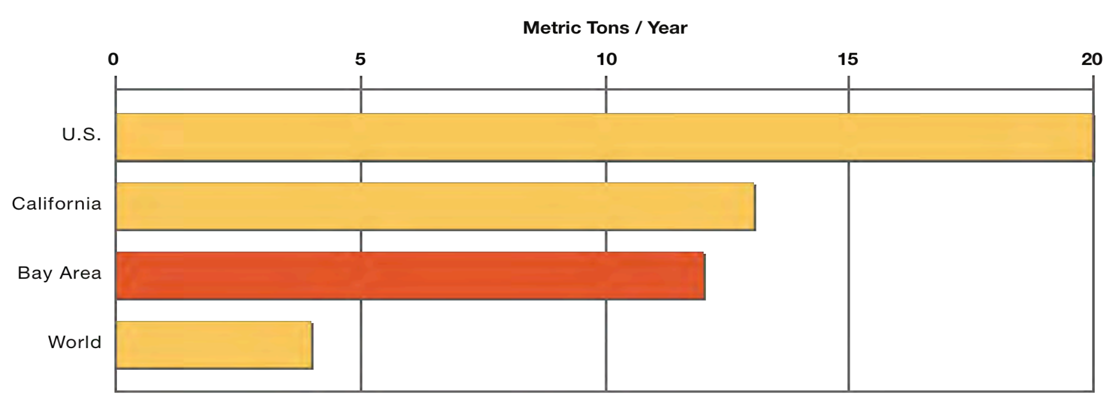
With so much at risk for California, on June 1, 2005, the Governor issued an Executive Order establishing GHG emission targets for the state. California strengthened its commitment to address climate change with the passage of Assembly Bill 32 (AB 32), the Global Warming Solutions Act of 2006. AB 32 requires the state to reduce GHG emissions to 1990 levels by 2020 and to 80 percent below 1990 levels by 2050 (CARB 2008).

On August 25, 2008, the State Assembly passed SB 375 and the Governor signed it into law on September 30th, 2008. The bill mandates an integrated regional land-use-and-transportation-planning approach to reducing GHG emissions from automobiles and light trucks, principally by reducing vehicle miles traveled. Within the Bay Area, the bill assigns responsibilities to the Association of Bay Area Governments (ABAG) and to the Metropolitan Transportation Commission (MTC). Both agencies are members of the Joint Policy Committee (JPC), which also includes the Bay Area Air Quality Management District and BCDC. The JPC developed a policy document to guide ABAG and MTC in fulfilling their responsibilities in collaboration with their JPC partners (JPC 2009).

Bay Area GHG Contributions. The Bay Area is a major contributor of GHG emissions. In order to understand how the Bay Area fits into the global emissions scheme, some context is necessary. The United States produces more CO_2 emissions per capita than any other country in the world and twice the emissions of most "developed" countries (Figure 1.1). California is the twelfth largest source of climate change pollutants in the world, ranked between South Korea and Italy, and emits more GHGs than most nations. When CO_2 is measured in per capita metric tons/year, the Bay Area is only slightly below the statewide average (Figure 1.2).

Figure 1.2 Bay Area Contribution to CO_2 Emissions (per Capita)

Source: USEIA, CA Climate Action Team, BAAQMD; Bay Area Air Quality Management District, 2007

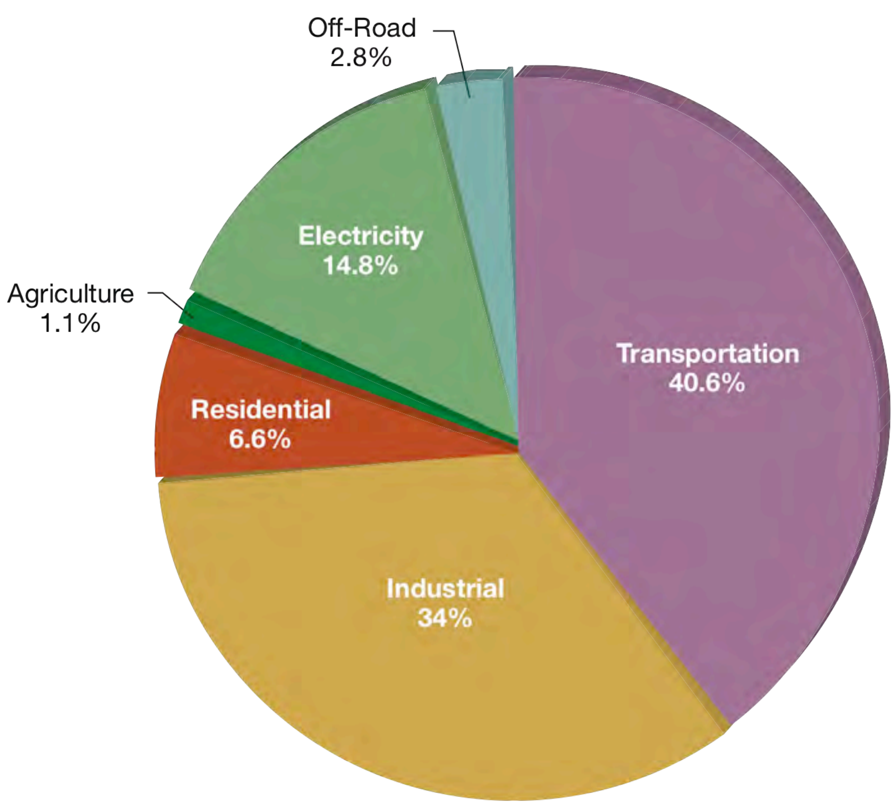


California's climate change emissions come primarily from fossil fuel combustion in the transportation sector, which makes up 41.2 percent of the state's GHG emissions. Energy production and industrial uses are other major contributors.

The Bay Area Air Quality Management District reports the Bay Area breakdown of climate change emissions is similar to the statewide breakdown. The two sectors with the highest emissions are transportation and industrial, which make up 40.6 and 34 percent of the total GHG emissions respectively (Figure 1.3).

Figure 1.3 Bay Area GHG Sources

Source: BAAQMD, 2007



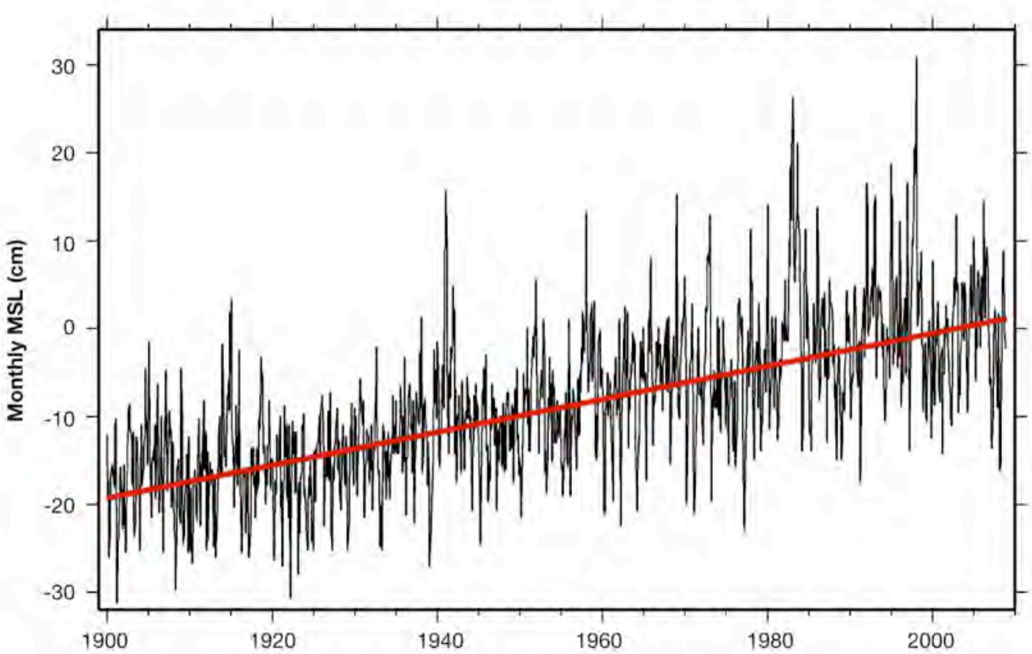
The JPC developed a strategy to address climate change, which reflects the diverse responsibilities of the four regional agencies that make up the JPC: the Bay Area Air Quality Management District, the Association of Bay Area Governments, the Metropolitan Transportation Commission, and BCDC. Given that transportation is the primary source of GHG emissions in the Bay Area, the JPC's climate change strategy includes numerous objectives aimed at reducing driving through a variety of methods, including focused growth and transit-oriented development and public transportation funding strategies, which all reduce the need to drive. BCDC is responsible for carrying out the elements of the strategy that address adapting to sea level rise and other Bay-related impacts of climate change.

Sea Level Rise

Warming of the planet causes sea level to rise and increases the potential for damaging floods that will affect coastal communities around the world. There are two major processes that contribute to global mean sea level rise, primarily by increasing the volume of water in the global ocean. Those processes are: (1) the addition of water from glaciers and ice sheets (land-based ice) (Bindoff et al. 2007); and (2) thermal expansion, which is when water expands as it warms, causing sea level to rise. These processes are complex and difficult to project into the future. While the melting of floating sea ice (e.g., icebergs) has significant adverse environmental impacts, it does not contribute additional water to the oceans and, therefore, does not directly contribute to global sea level rise.

Figure 1.4 Sea Level Rise in San Francisco Bay

Source: Cayan et. al. 2006; San Francisco Tide Gauge

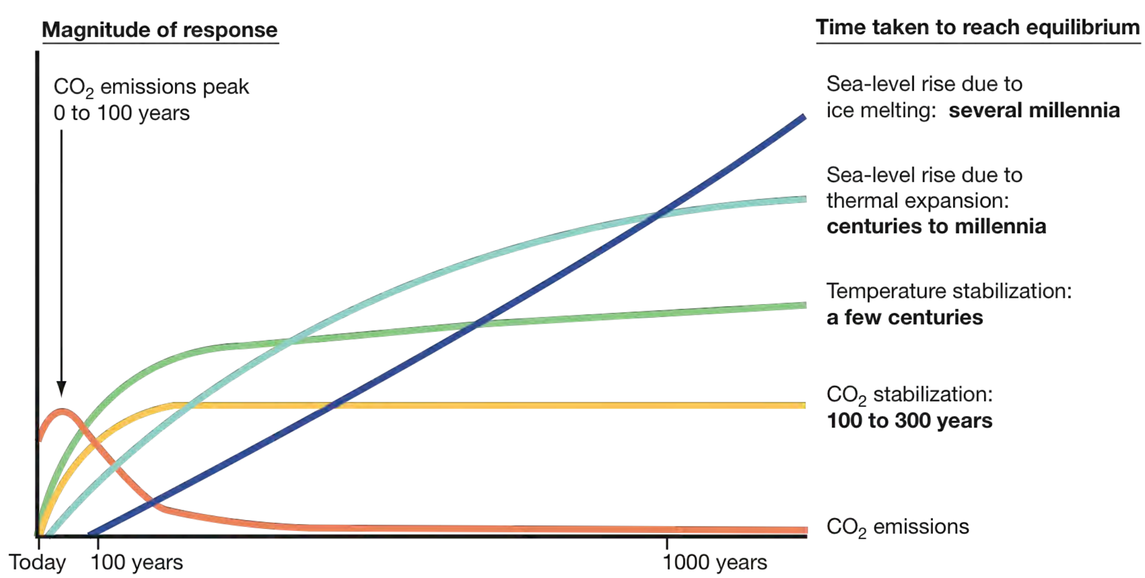


The San Francisco tide gauge at Fort Point is the longest continually monitored gauge in the United States. Sea level rise trends measured at this tide gauge and two other long-running tide gauges on the west coast show sea level rise of nearly 7.9 inches (19 cm) per century or 0.08 inches (2 mm) per year (Figure 1.4) (Cayan et al. 2006(b)). This rate of sea level rise is consistent with global sea level rise.

The rate of global sea level rise is increasing. The 20th century rise was estimated to be 6.7 inches (17 cm) or 0.067 inches (1.7 mm) per year on average. From 1961 to 2003, GHG emissions had been accumulating long enough to increase the rate of rise to 0.07 inches (1.8 mm) per year (IPCC 2007). Analyses of observed sea level rise over the last approximately 15 years show that the rate of rise increased significantly above that of previous decades (Church and White 2006). The IPCC concluded that from 1993-2003, the rate of sea level rise increased to about 0.12 inches (3.1 mm) per year (IPCC 2007), demonstrating the likely effect of human-induced warming on sea level.

Figure 1.5 Long Term Trend in Sea Level Rise

Source: Intergovernmental Panel on Climate Change; Department of Water Resource, based on IPCC



No matter how effectively the world mitigates GHG emissions, oceans have already warmed, sea levels are already rising at accelerated rates, and are likely to continue rising. The ocean has been absorbing more than 80 percent of the heat added to the climate system and has already warmed to depths of at least 9,843 feet (3000 m) (IPCC 2007). Perhaps the most notable finding from the IPCC is that the effects of GHG emissions will continue long after emissions are reduced. The IPCC projects that global temperature will continue rising for a few centuries before stabilizing. Sea level rise from thermal expansion will continue for centuries to millennia. Sea level rise from ice-sheet melting will continue for several millennia (Figure 1.5) (IPCC 2007).

Ice-Sheet Melting and Uncertainty. There is a great deal of uncertainty surrounding the future contributions to global sea level rise from the melting of the Greenland and Antarctic ice sheets. Most scientists agree that the rate of ice-sheet melt will accelerate as melt-water seeps through cracks in the ice sheet and causes further acceleration of melting and movement of the ice sheet toward the sea. The IPCC concluded that losses from the ice sheets have "very likely" contributed to sea level rise from 1993 to 2003. (In IPCC terminology, very likely means a greater than 90 percent probability of occurring.) However, there is no scientific consensus on how to model or project future rates of ice-sheet melt.

The nature of ice-sheet melt is not fully understood. Observations show that as ice melts, the melt water runs over ice and causes it to melt at a faster rate, carving deep crevices and weakening the ice. Further, the meltwater runs under the ice sheets and weakens buttressing ice shelves, which can cause large portions of ice sheets to collapse. The central question is whether ice-sheet melting will accelerate by an order of magnitude and whether this could occur in a timeframe of hundreds or thousands of years (Oppenheimer 2006).

Warming of 3.6-5.4° F (2-3° C) could cause melting that would induce "multiple positive feedbacks, including reduced surface albedo, loss of buttressing ice shelves, [and] dynamical response of ice streams to increased melt-water" (Hansen 2006). Surface albedo is a ratio of incoming radiation that is reflected to that which is absorbed. White ice has a high albedo—it reflects most solar radiation, which means that as sea-ice melts, the oceans absorb more heat from radiation. Due to these feedback effects, some scientists believe that the ice sheet response could move beyond a point of equilibrium within a few centuries (Hansen 2006). However, even with ice-sheet melt, sea level rise is very unlikely to exceed 6.6 feet (200 cm) by 2100 (Pfeffer et al. 2008).

Although numerical modeling remains inadequate to project future ice-sheet melt, additional studies of the last interglacial period confirm that the warming needed to cause shrinkage of the Greenland Ice Sheet averaged less than 6.3° F (3.5° C) (Overpeck et al. 2006). Further, recent observations and innovations have improved modeling of ice-sheet behavior, but models still do not assess feedback loops and, therefore, fail to factor the interrelatedness of ice-sheet melting, ocean circulation, and climate change (Alley et al. 2005). The AR4 projections for warming in the years 2090-2099 ranged from 3.2° F (1.8° C) for the lowest emissions scenario (B1) to 7.2° F (4° C) for the highest emissions scenario (A1FI). Therefore, mid and higher emissions scenarios produce temperature increases by the end of the century that would, at a minimum accelerate ice-sheet melt.

Sea Level Rise Scenarios

There is broad scientific consensus that the rate of sea level rise has increased with higher global surface temperatures. The point of debate is what the rate of sea level rise will be in the future. Similar to the approach used to evaluate global warming, using scenarios of future sea level rise enable us to understand the risks and develop a strategy that will support the appropriate responses. Scenarios of future sea level rise enable us to understand the risks and develop a framework now that will support the appropriate responses.

In 2007, German scientist, Stefan Rahmstorf developed an empirical approach to projecting future sea level rise by calculating the relationship between sea level rise and global mean surface temperature. Rahmstorf first determined the historic trend in the relationship and then projected that trend into the future using the IPCC's projected temperature increases associated with the SRES scenarios: 2.5°F (1.4° C) for the lowest emissions scenario to 10.4° F (5.8° C) for the highest emissions scenario (Rahmstorf 2007). Rahmstorf's corresponding estimates of sea level rise by 2100 range from 20 inches (50 cm) to 55 inches (140 cm) respectively.

Research funded by the CAT for the 2009 report to the Governor used the A2 and B1 scenarios and Rahmstorf's methodology to project sea level rise in California in 2050 and 2099. These sea level rise projections are also adjusted to include the effects of dams on sea level rise (Cayan et al. 2009). Past construction of dams and reservoirs may have stored enough water worldwide to mask acceleration in the rate of sea level rise prior to the notable acceleration detected in 1993. Most dams were constructed during the 1950s through the 1970s. Building of dams for additional upland water storage has since slowed, which means that sea level rise may now be accelerating faster than the IPCC and scientists have predicted (Chao 2008). The CAT-funded research estimated that sea level would increase between 12 and 18 inches (30 and 45 cm) by 2050 and between 20 and 55 inches (50 and 140 cm) by 2099.

The Delta Vision Blue Ribbon Task Force established by Governor Schwarzenegger to develop a strategic management plan for the California Delta, employed an Independent Science Board (ISB) to review literature and provide recommendations on sea level rise. The ISB found that: (1) the current IPCC projections are conservative and underestimate recently measured SLR; (2) empirical models, such as Rahmstorf's empirical method, yield significantly higher estimates of sea level over next few decades and are better for short to mid-term planning; and (3) neither the IPCC nor Rahmstorf account for accelerating contributions from ice sheet melting, which will likely contribute significantly to future sea level rise with the potential for very rapid increases of up to a meter by 2100. Based on these findings, the ISB recommended adopting an estimated rise in sea level of 55 inches (140 cm) by 2100 and recommended adopting a sea level rise estimate for 2050 as well.

On November 14, 2008, the Governor issued Executive Order S-13-08, that, in part, directed state agencies to consider a range of sea level rise scenarios for the years 2050 and 2100 to assess project vulnerability, reduce expected risks, and increase resiliency to sea level rise. The order also directed agencies to request that the National Academy of Sciences convene an independent panel to prepare a "California Sea Level Rise Assessment Report." In advance of the National Academy of Sciences report, in 2010, senior staff from 16 state agencies of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) reached agreement on a Sea-Level Rise Interim Guidance Document, with science-based input from the California Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust. The CO-CAT recommended that state agencies use the ranges of sea level rise (SLR) presented in a paper by Vermeer and Rahmstorf (2009), adjusted to use 2000 rather than 1990 as the baseline, as a starting point (Table 1.2), "and select SLR values based on agency and context-specific considerations of risk tolerance and adaptive capacity."

Table 1.2. CO-CAT Sea Level Rise Scenarios using 2000 as the Baseline

Year		Average of Models	Range of Models
2030		7 in (18 cm)	5-8 in (13-21 cm)
2050		14 in (36 cm)	10-17 in (26-43 cm)
2070	**Low**	23 in (59 cm)	17-27 in (43-70 cm)
	Medium	24 in (62 cm)	18-29 in (46-74 cm)
	High	27 in (69 cm)	20-32 in (51-81 cm)
2100	**Low**	40 in (101 cm)	31-50 in (78-128 cm)
	Medium	47 in (121 cm)	37-60 in (95-152 cm)
	High	55 in (140 cm)	43-69 in (110-176 cm)

The table was published with the following note: “These projections do not account for catastrophic ice melting, so they may underestimate actual SLR. The SLR projections included in this table do not include a safety factor to ensure against underestimating future SLR. For dates after 2050, three different values for SLR are shown based on low, medium, and high future greenhouse gas emission scenarios. These values are based on the Intergovernmental Panel on Climate Change emission scenarios as follows: B1 for the low projections, A2 for the medium projections and A1FI for the high projections.” The CO-CAT’s Sea Level Rise Interim Guidance document was endorsed by a resolution of the California Ocean Protection Council in 2011. The interim guidance will be updated consistent with the National Academy of Sciences 2012 report, and other forthcoming studies.

Sea Level Rise and Extreme Events. Most shoreline damage from flooding will occur as a result of storm activity in combination with higher sea level. Climate change-induced sea level rise will combine with the key factors that currently contribute to coastal flooding: high tides, storm surge, high waves and high runoff from rivers and creeks (Cayan et al. 2009).

Storms and flooding in California occur during the winter from November to April and are influenced by several climate patterns, most prominently the El Niño Southern Oscillation (ENSO) (Miller 2003, Cayan et al. 2008). Every two to seven years, ENSO alternates between two phases, La Niña and El Niño. In contrast to La Niña, “El Niño years” generally result in persistently low air pressure, greater rainfall, and high winds (Cayan et al. 2008), all of which contribute greatly to coastal flooding hazards.

Low air pressure causes an instantaneous rise in sea level above predicted tides, referred to as storm surge (Cayan et al. 2008). During storms with high rainfall, Bay tributaries flood, elevating flood stage in creeks and rivers beyond the initial storm surge, and low air pressure increases wind activity, generating erosive waves superimposed on the already high sea level (Bromirski and Flick 2008). This combination of factors, during an El Niño event in the winter of 1982-83, caused over $500 million in damage in the San Francisco Bay Area (ABAG 2006).

As sea level rises, storm-induced flooding will become more frequent and more hazardous to public health and safety. Over the recent period of accelerated sea level rise (1993 to 2003), there was an increase in both the number of storm surge events and high tides exceeding previously observed extremes. This increase in storm activity and extreme tides is projected to continue into the future (Cayan et al. 2008, Bromirski and Flick 2008). Should the state’s water reservoirs lack capacity to capture rainfall and earlier Sierra snow melt, water managers will need to release flows through the Delta during winter months, resulting in even higher water levels in the Delta and Suisun Marsh (Knowles and Cayan 2002, Cayan et al. 2008).

Different regions of the Bay may be more vulnerable to these floods than others (see Figure 1.6 for Bay regions). Tides in the South Bay are higher than the ocean and other areas of the Bay, which will amplify storm surge events (PWA 2005). The combined effects of sea level rise, storm surge and river flooding may result in water levels elevated as high as 51 inches for a period of 10 to 12 hours in the Delta and Suisun Marsh region (Bromirski and Flick 2008), an area where much of the land is already below mean tide elevation and is surrounded by fragile levees (DWR and DFG, 2008).

Therefore, significant flooding impacts from sea level rise can be expected during the early part of this century, due to winter storms and sea level rise.

BCDC Policy Analysis. Most of the permit applications that BCDC receives are for projects with a lifespan of at least 50 – 90 years. For the purposes of this policy analysis and to provide timeframes that are most relevant to the Commission's regulatory and planning functions, a mid-century and end-of-century sea level rise projection are used. The shorter timeframe is most applicable for projects, such as institutional or commercial development. The longer timeframe attempts to anticipate future impacts within a reasonable degree of certainty for large-scale projects with longer life cycles, such as new neighborhoods or major public infrastructure projects. While these are only projections, not predictions, the necessary response to rising sea level may be similar whether sea level rises more slowly or more quickly. The primary difference will be in the scale and speed of response that will be required.

When BCDC initiated its effort to amend the Bay Plan to address climate change in 2009, the State of California was still in the process of formulating statewide policy direction for adapting to sea level rise, as described above. This report assesses vulnerability using 16 inches of sea level rise at mid-century and 55 inches at the end of the century because: (1) given the potential for sea level rise to threaten lives and damage property and natural resources in the Bay, it is prudent to use a conservative scenario; and (2) it is consistent with other state efforts. The sea level rise projections used in this report fall within the ranges that were subsequently endorsed by the California Ocean Protection Council in 2011, i.e., 10-17 inches at mid-century and 31-69 inches at end of century. A number of terms that are common in discussions of adaptation are defined in Box 1.1.

Box 1.1. Definitions

Resilience: The ability of a system to absorb and rebound from the impacts from weather extremes, climate variability, or change and to continue functioning (Luers and Moser)

Adaptation: Actions in response to potential or experienced impacts of climate change that lead to a reduction in risks or a realization of benefits.

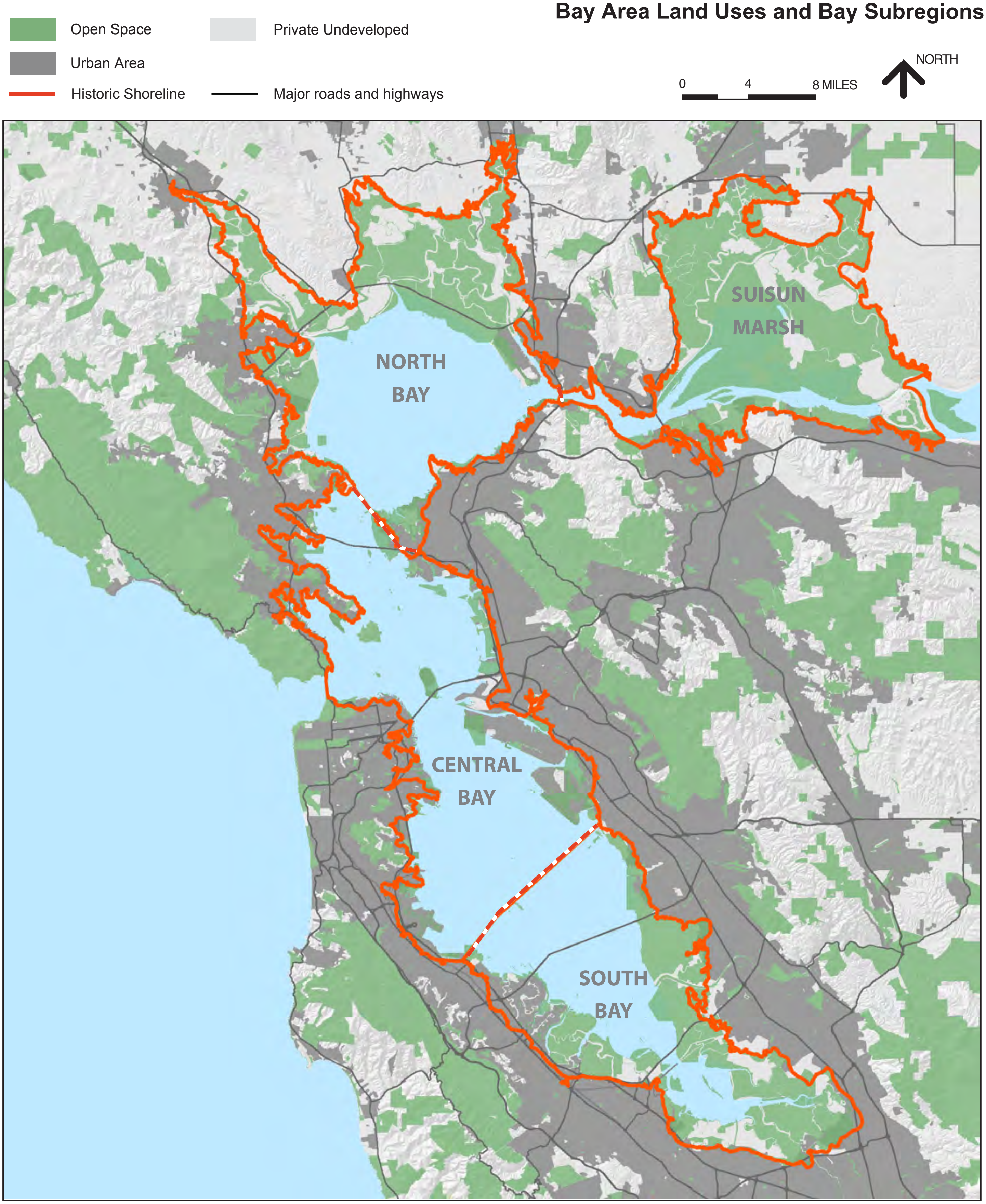
Mitigation: Actions that reduce the emission of greenhouse gases into the atmosphere or enhance their sequestration and thereby reduce the probability of reaching a given level of climate change.

Vulnerability: The extent to which a natural or social system is susceptible to the adverse effects of climate change, climate variability and extremes—a function of risk and adaptive capacity.

Adaptive Capacity: The ability of a system to adjust or respond to climate change, climate variability and extremes, to accomplish the following: (1) moderate potential damages; (2) take advantage of new opportunities arising from climate change; or (3) accommodate the impacts.

Figure 1.6

Bay Area Land Uses and Bay Subregions



SOURCE: Urban and open space (GreenInfo 2004), Regions (EcoAtlas 2009)

Vulnerability Assessment

The following three chapters describe the vulnerability assessment performed for this report. The assessment is both qualitative and quantitative, including a review of literature and original analysis using GIS sea level rise data. It focuses on three planning areas or systems: the shoreline environment, the Bay ecosystem, and governance. Key sectors within each system are identified and analyzed to ascertain their current and expected challenges and projected climate change impacts. Based on the information available, which in some cases is limited, and recognizing the general uncertainty involved in projecting climate change impacts, a vulnerability assessment is performed that identifies the degree of sensitivity, adaptive capacity, and vulnerability. This assessment is summarized at the end of each chapter based on a standard methodology developed through The Climate Project for King County in Washington (The Climate Project 2007).

The emphasis of this assessment is regional, which may limit its application to specific projects or limited areas, such as the shoreline within any given city. While the assessment is valuable, it is limited by the information available and the uncertainty regarding future change. To make the assessment feasible, BCDC worked with the California Energy Commission's Public Interest in Energy Research (PIER) program to commission the development of sea level rise data and a cost assessment of potential impacts from sea level rise.

The sea level rise data were provided by the United States Geologic Survey (USGS), which used a hydrodynamic computer model to identify areas at risk in two scenarios, 16 inches and 55 inches of sea level rise. The USGS assembled the best available digital elevation data for the Bay shoreline into a regional grid. Historic (1996-2007) tidal data were used to determine the highest average monthly tide, then the sea level rise estimates were integrated into the tidal datum (Knowles 2008)[1].

While the data are the best available for mapping and analysis of shoreline areas that may be exposed to sea level rise, there are limitations for their use. The data were developed using an average of the highest tide in each month, which captures most storm surge within a year. However, the data do not include wave activity that occurs during storms, nor the highest tides.

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[1] The data for this assessment was developed by USGS analyzing the area vulnerable to inundation from the average highest monthly tide, factoring in 16 and 55 inches (40 and 140 cm) of sea level rise. The data used by Knowles and the Pacific Institute in two recent reports on sea level rise in San Francisco Bay are based on an average highest yearly tide, factoring in the same two scenarios. However, the difference between these data is insignificant. Although the average yearly high tide inundates an area approximately 1% (2,000 acres) greater than the average monthly high tide, the additional areas affected are evenly distributed around the Bay and are barely distinguishable on maps. Furthermore, the difference may likely be attributable to the resolution of the elevation data upon which the USGS work is based. Consultation with USGS and other experts confirmed that the difference is well within the range of uncertainty of the data and the analyses.

Consequently, an area that floods from wave activity during winter storms, such as the Embarcadero in San Francisco, is not considered exposed. Importantly, where the elevation of land is below the water level, it is shown as potentially exposed to sea level rise, whether or not shoreline protection exists. This is because adequate information was not available on levee heights or location. Additionally, the data does not indicate the depth of flooding. Low-lying land or depressions in upland areas may also appear to be exposed to inundation, even if there is no path for water to reach the isolated, low-lying area. Despite these limitations, the data is useful for drawing general conclusions about the region's vulnerability to sea level rise and storm surge.

Analysis using the data shows that approximately 180,000 acres (281 square miles) of shoreline are potentially exposed to more flooding or permanent inundation with 16 inches (40 cm) of sea level rise and approximately 213,000 acres (332 square miles) are vulnerable at 55 inches (140 cm) (Figures 1.7-1.18). With 55 inches of sea level rise, an additional 33,000 acres (51 square miles) are potentially exposed. These additional areas are scattered around the perimeter of the shoreline potentially exposed to flooding or more frequent inundation under the 16-inch sea level rise scenario.

The area inundated in the 16-inch projection is already subject to some degree of flood risk. Analysis performed by USGS indicates that the area inundated under the lower projection is roughly equivalent to the area exposed to a 100-year high water event in 2000, not taking existing and planned shoreline protection into account (Knowles 2008). In other words, the area exposed to today's extreme flood event is roughly equivalent to the area potentially exposed to regular tidal inundation by mid-century (Figure 1.19).

Vulnerability from Subsidence. Relative sea level rise, rather than global sea level rise alone, provides the most accurate measure of water level along the Bay shoreline. Relative sea level rise is the sum of global sea level rise and the change in vertical land motion. Thus, if sea level rises and the shoreline subsides[2], the relative rise in sea level could be greater than the global rise. For many years the South Bay shoreline, including urbanized areas and salt ponds, experienced high rates of subsidence from groundwater depletion, which has now apparently stopped. Where subsidence continues, such as in areas where peat soils oxidize, relative sea level rise could cause more significant shoreline flooding in those areas than it would if the

[2] Subsidence, or sinking of the land surface, is generally caused by: vertical motion along a fault line, applying loads to incompetent soils, oxidation of organic matter in soils, or groundwater withdrawal from the subsurface of the land resulting from compaction.

shoreline land mass remained at a constant level, or rose (BCDC 1988). As rates of global sea level continue to increase with climate change, at some point, the rate of vertical land movement in the Bay Area will become less significant in determining the impact of sea level rise. However, areas that have subsided may be particularly vulnerable to sea level rise and extreme events.

The Suisun Marsh is one area of the Bay where relative sea level rise is significant, due to ongoing subsidence. When managed wetlands (wetlands behind levees) such as those located in the Suisun Marsh are allowed to dry out, the organic matter in the soil oxidizes. Loss of this organic matter may lead to local and regional ground subsidence. The continuing subsidence of managed wetlands can affect levee stability and increase the risk of failure (DWR, 1995; Mount and Twiss, 2005). Levee failure during floods in the Suisun Marsh and the Delta will cause saltwater intrusion into groundwater aquifers, saltwater contamination of agricultural lands, and changes to the salinity of freshwater and brackish ecosystems.

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Figure 1.7

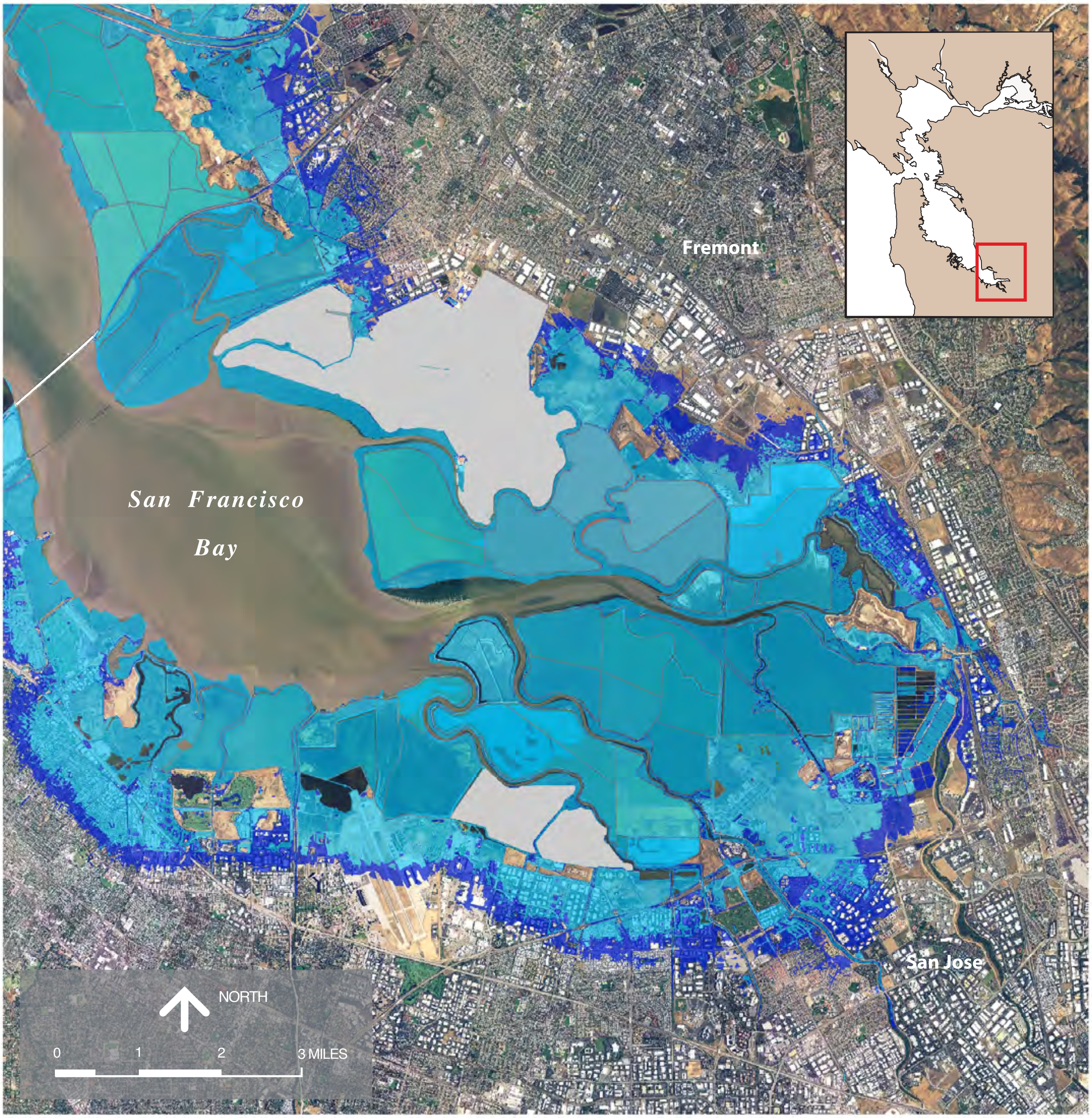
Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

No data

South Bay
Shoreline Areas Potentially Exposed to Sea Level Rise

DISCLAIMER: *Inundation data does not account for existing shoreline protection or wave activity. These maps are for informational purposes only. Users agree to hold harmless and blameless the State of California and its representatives and its agents for any liability associated with the use of the maps. The maps and data shall not be used to assess actual coastal hazards,insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by the Federal Emergency Management Agency (FEMA).*



Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

Figure 1.8

Central Bay South
Shoreline Areas Potentially Exposed to Sea Level Rise

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

No data

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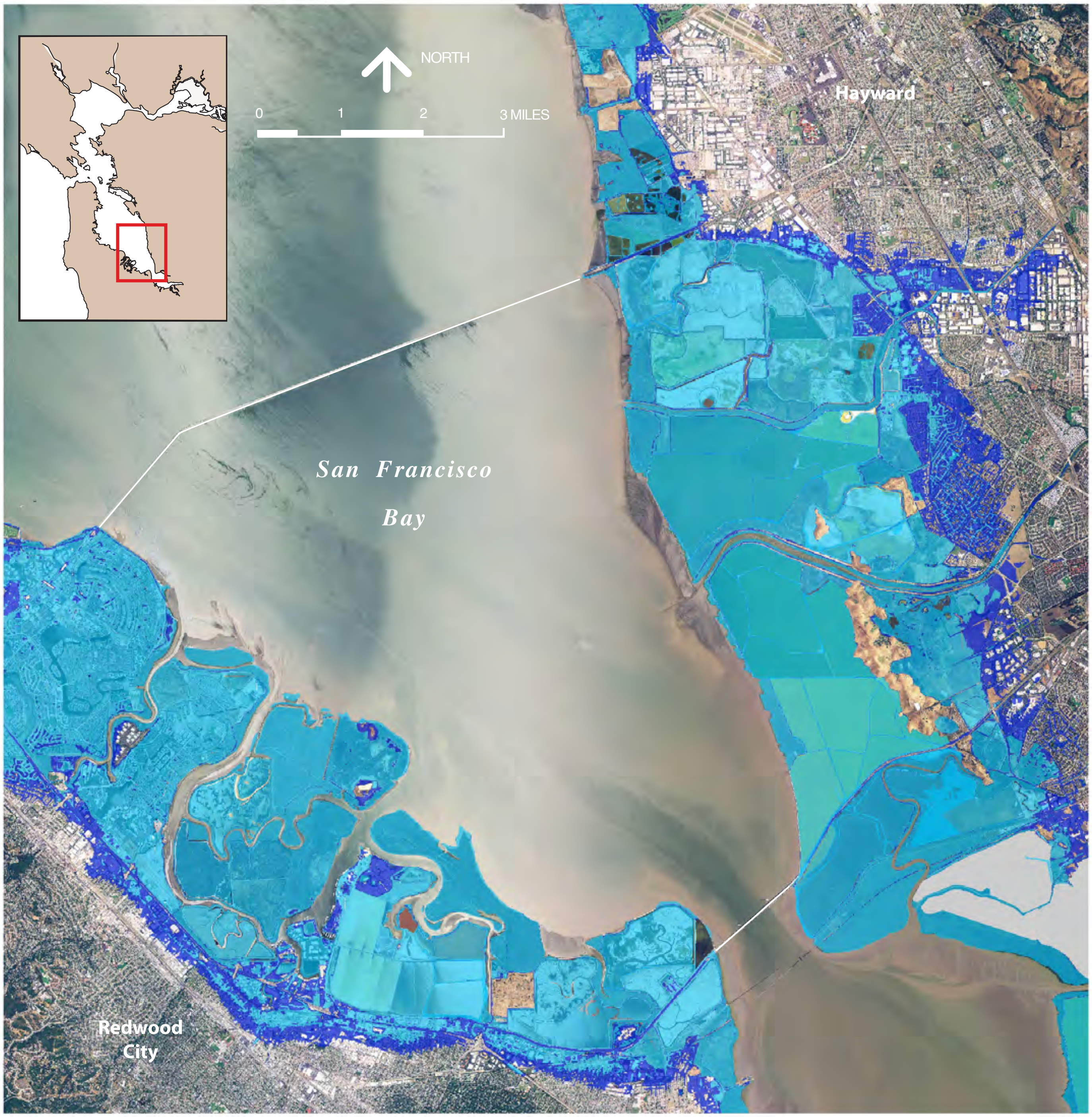

Sea level rise data provided by:

USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

Central Bay West Shore Shoreline Areas Potentially Exposed to Sea Level Rise

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

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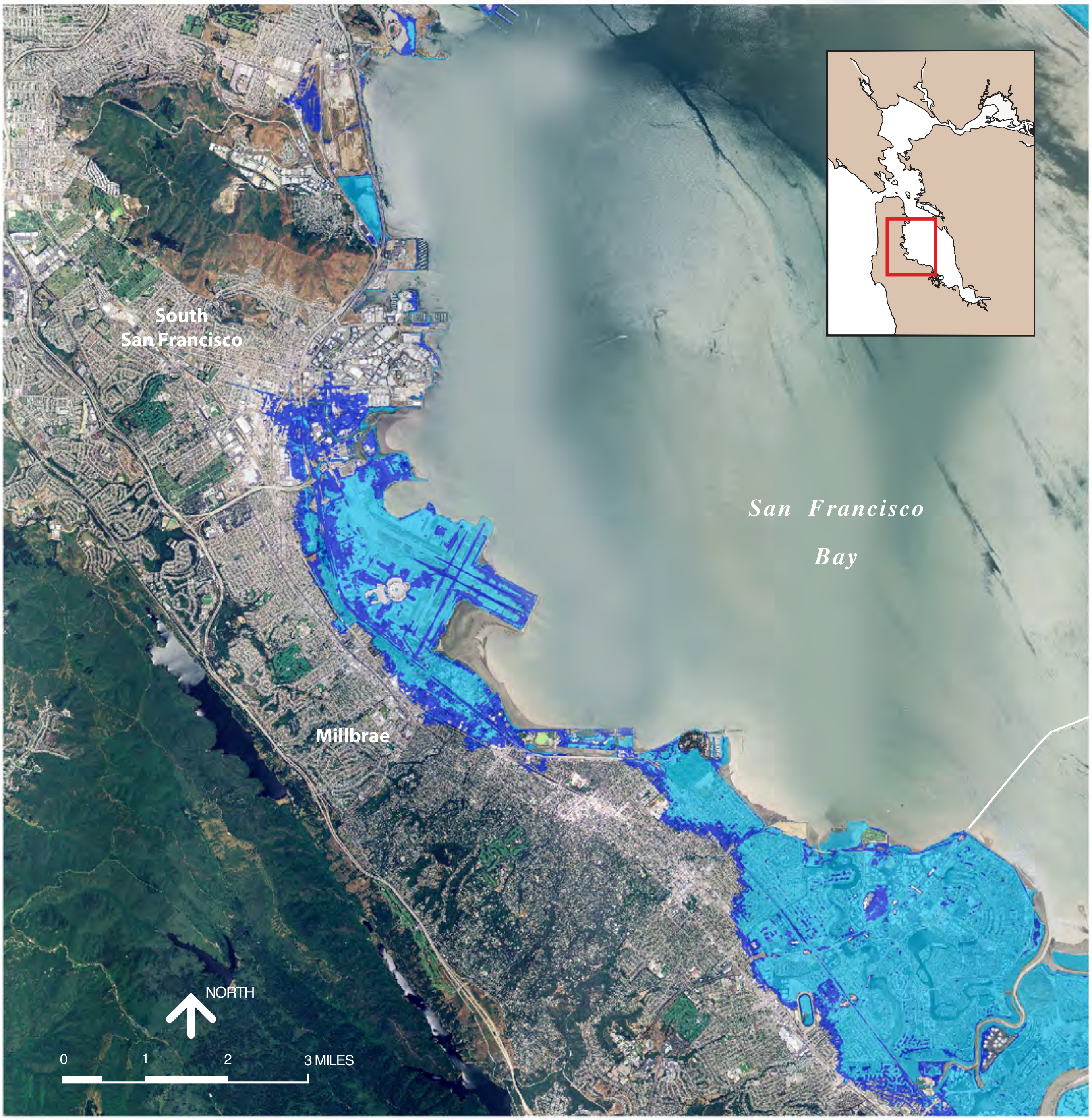

Sea level rise data provided by: USGS science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

Figure 1.10

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Central Bay East Shore
Shoreline Areas Potentially Exposed
To Sea Level Rise

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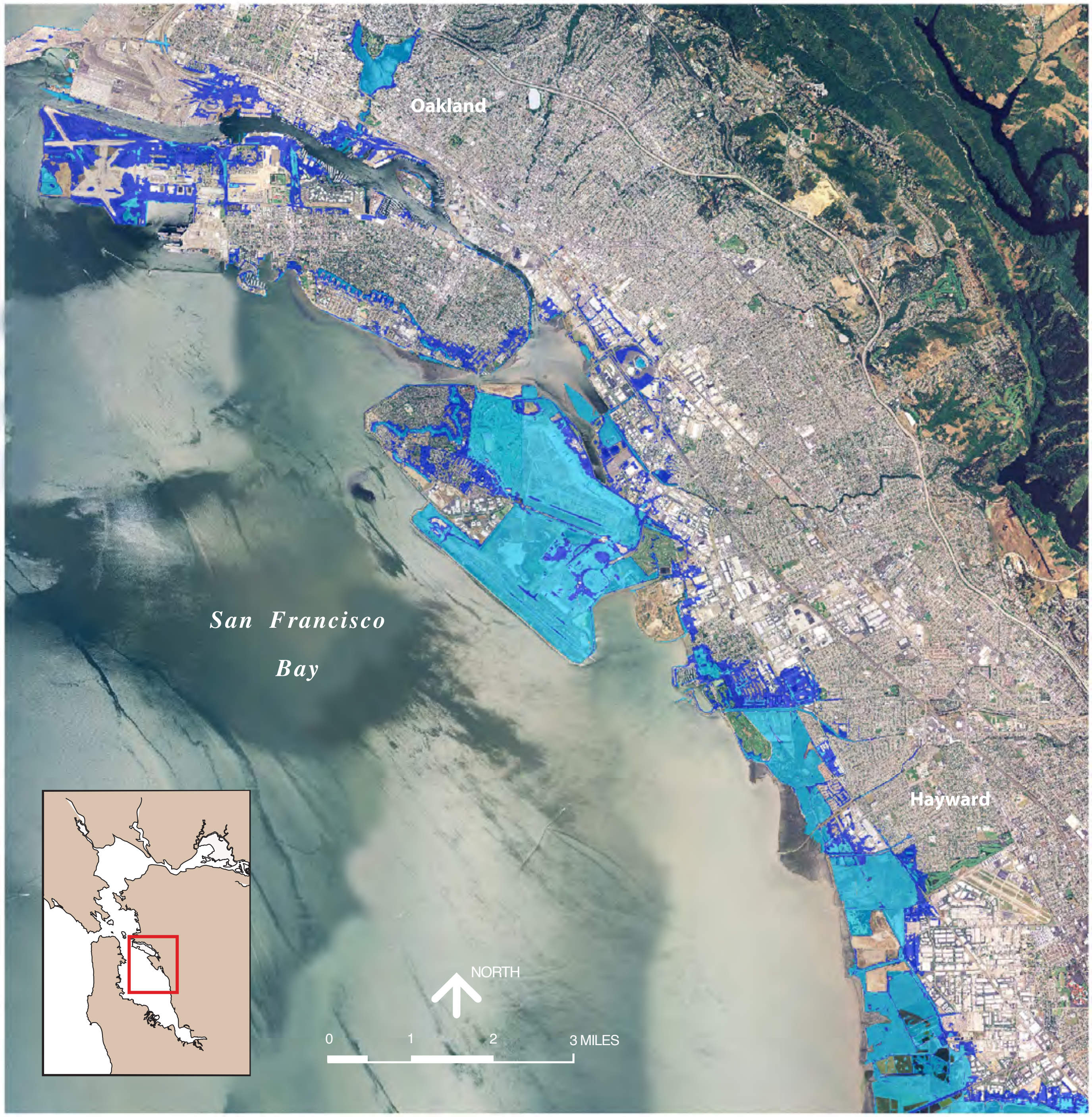

Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

Central Bay
Shoreline Areas Potentially Exposed to Sea Level Rise

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

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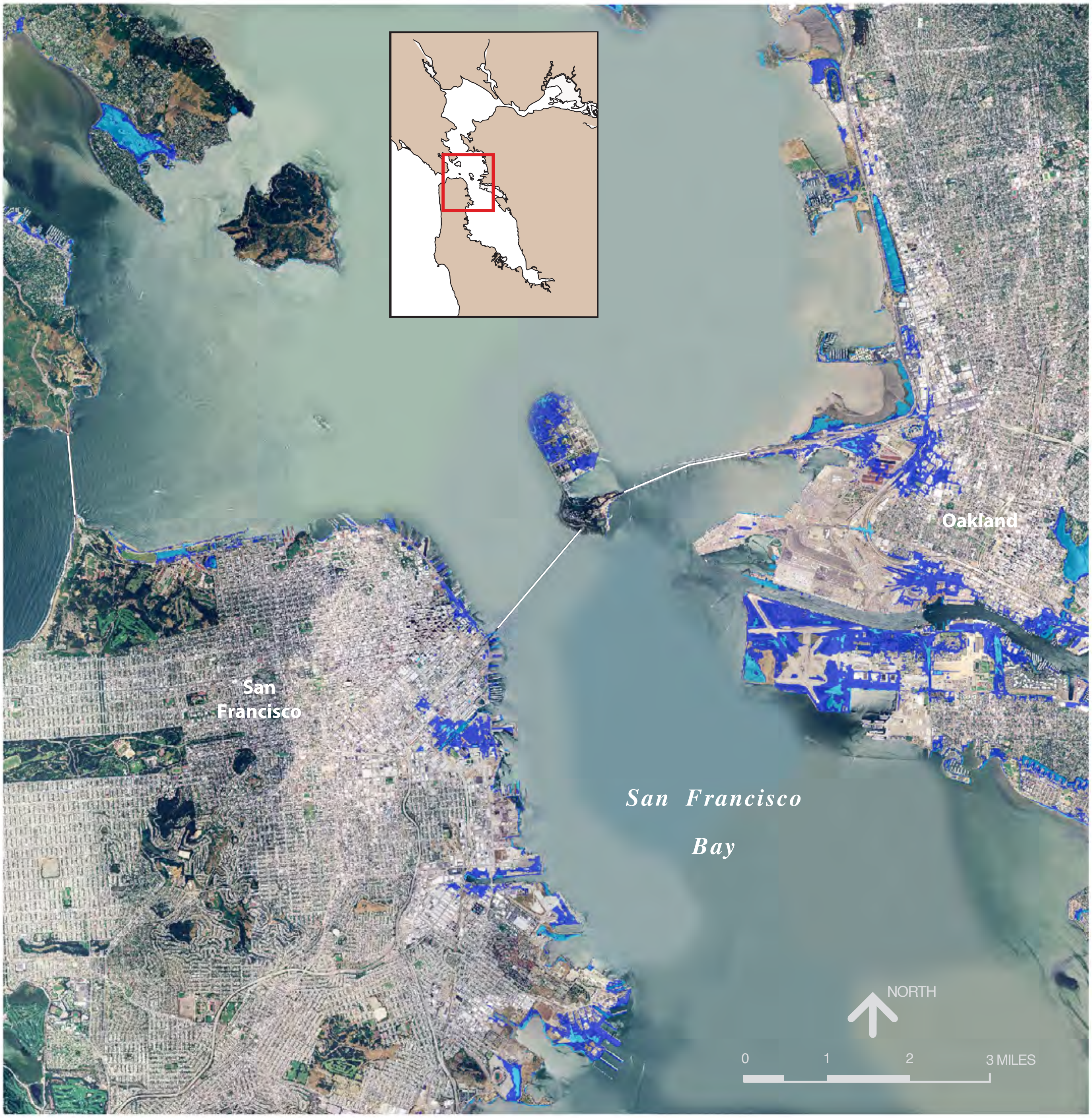

Sea level rise data provided by:

USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

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Figure 1.12

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Central Bay North Shoreline Areas Potentially Exposed to Sea Level Rise

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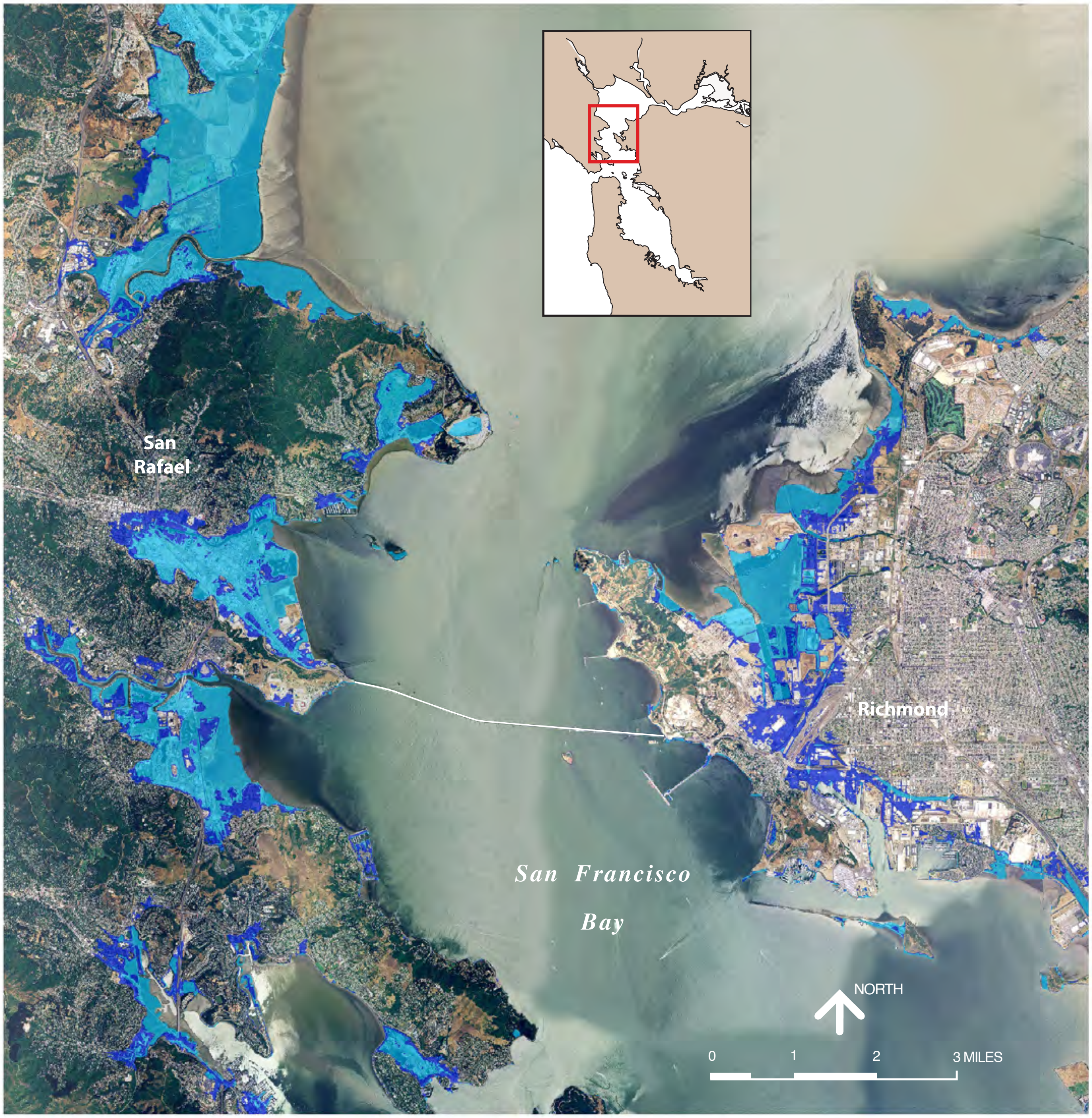

Sea level rise data provided by:

USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

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Figure 1.13

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Petaluma River
Shoreline Areas Potentially Exposed to Sea Level Rise

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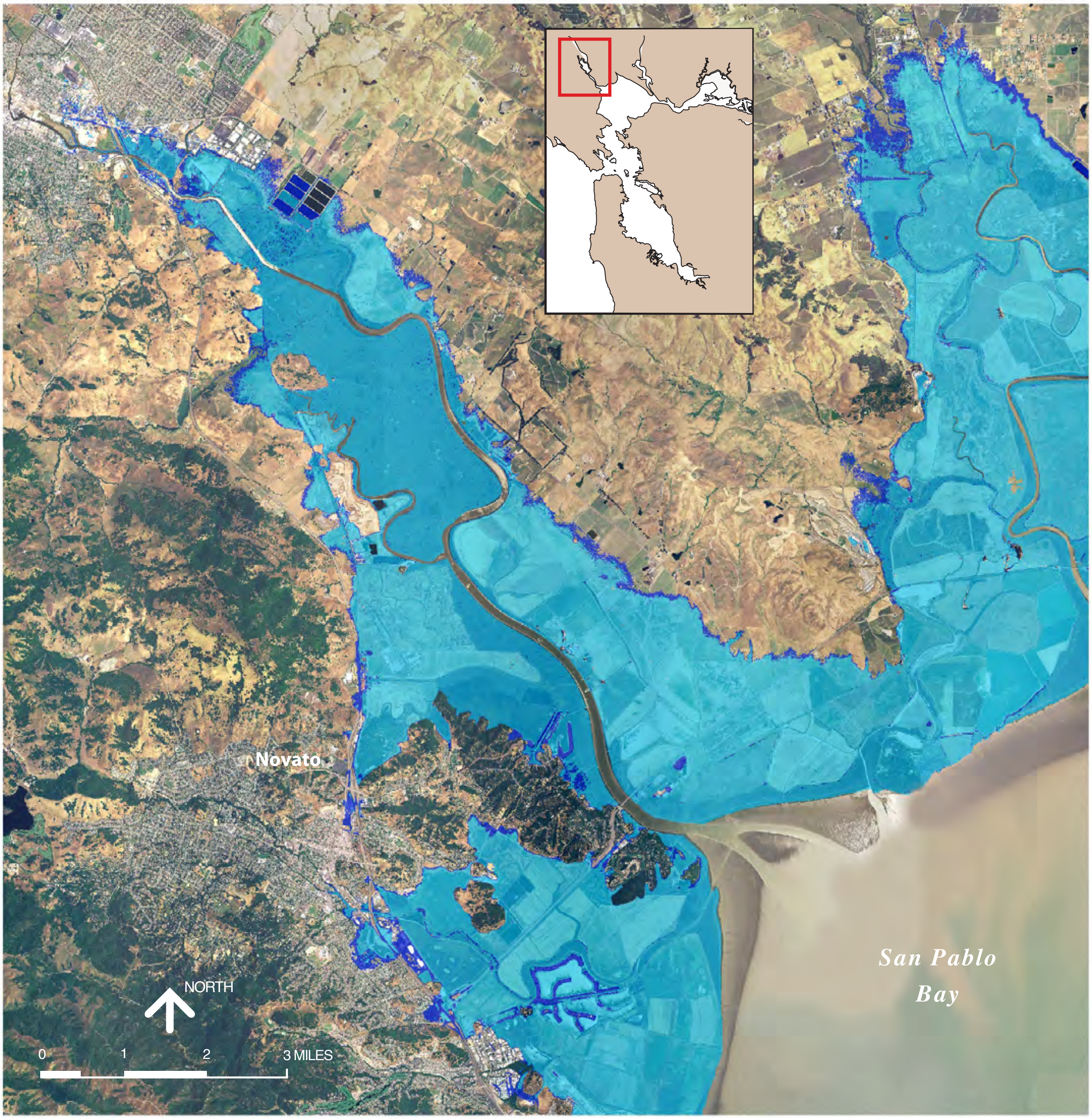

Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

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Figure 1.14

Napa River
Shoreline Areas Potentially Exposed to Sea Level Rise

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

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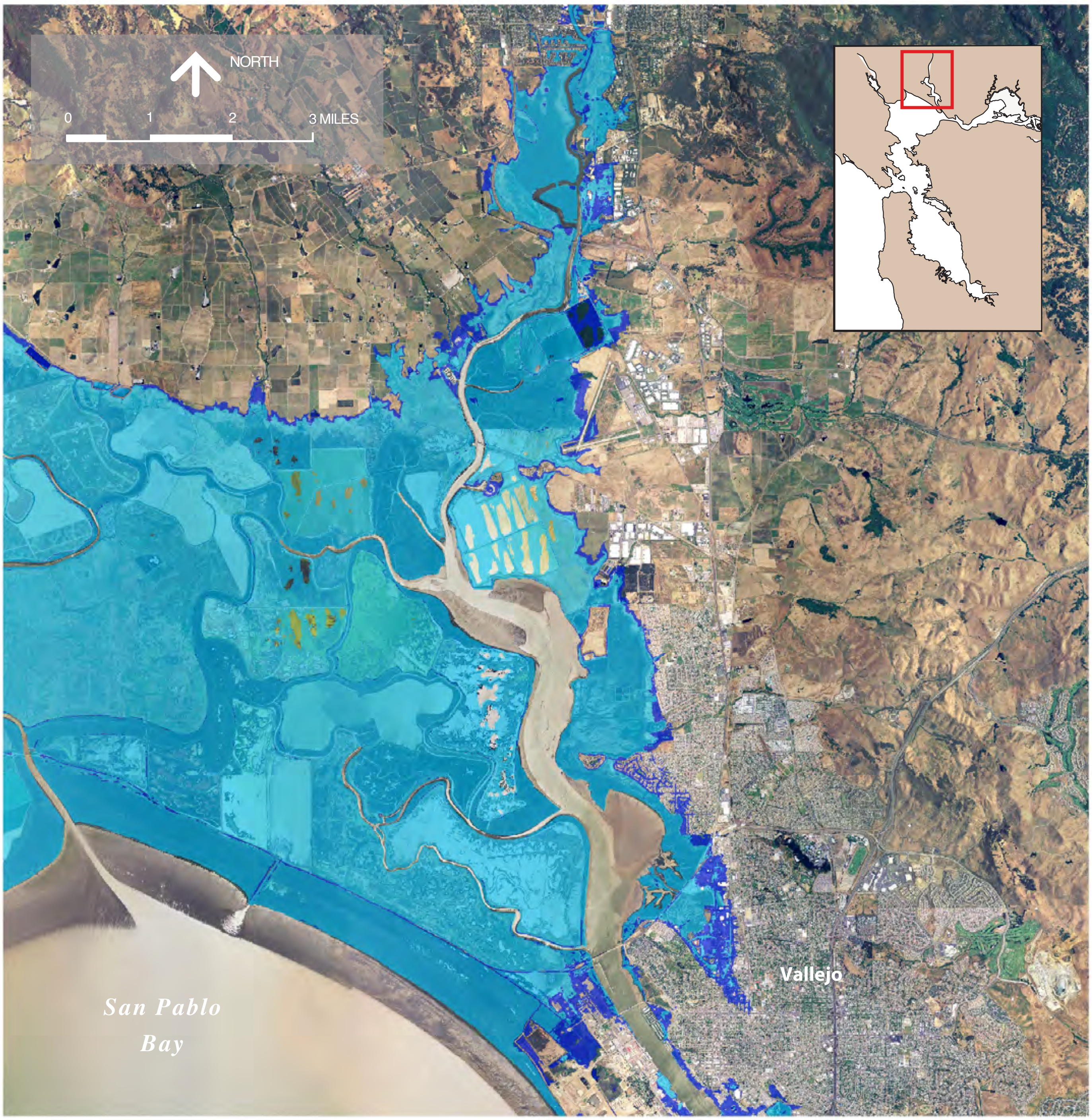

Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

San Francisco Bay
Conservation and Development Commission

Figure 1.15

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

San Pablo Bay/Carquinez Strait Shoreline Areas Potentially Exposed to Sea Level Rise

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Sea level rise data provided by:

USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

Figure 1.16

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Grizzly Bay
Shoreline Areas Potentially Exposed to Sea Level Rise

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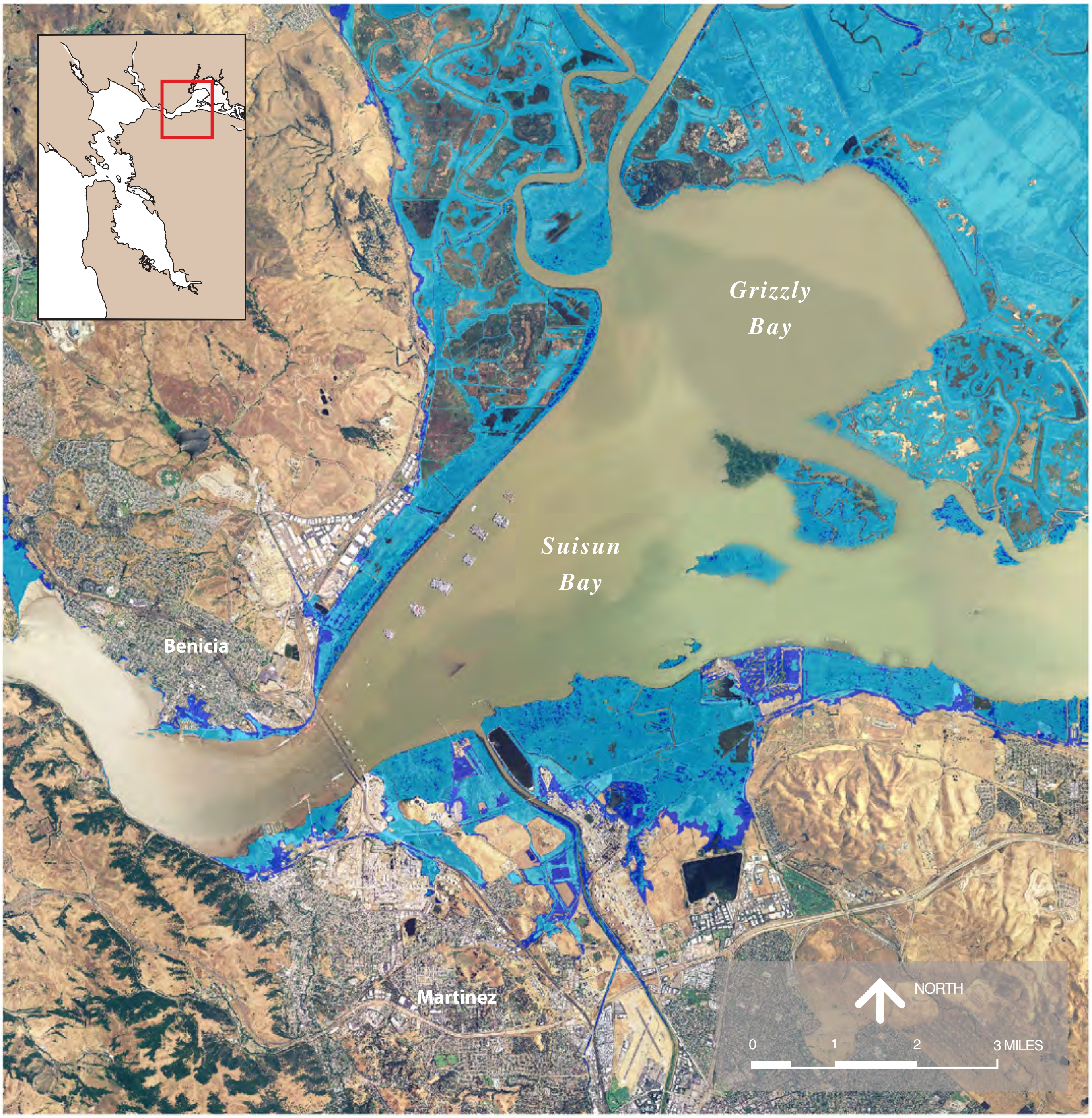

Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

San Francisco Bay
Conservation and Development Commission

Figure 1.17

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Honker Bay
Shoreline Areas Potentially Exposed to Sea Level Rise

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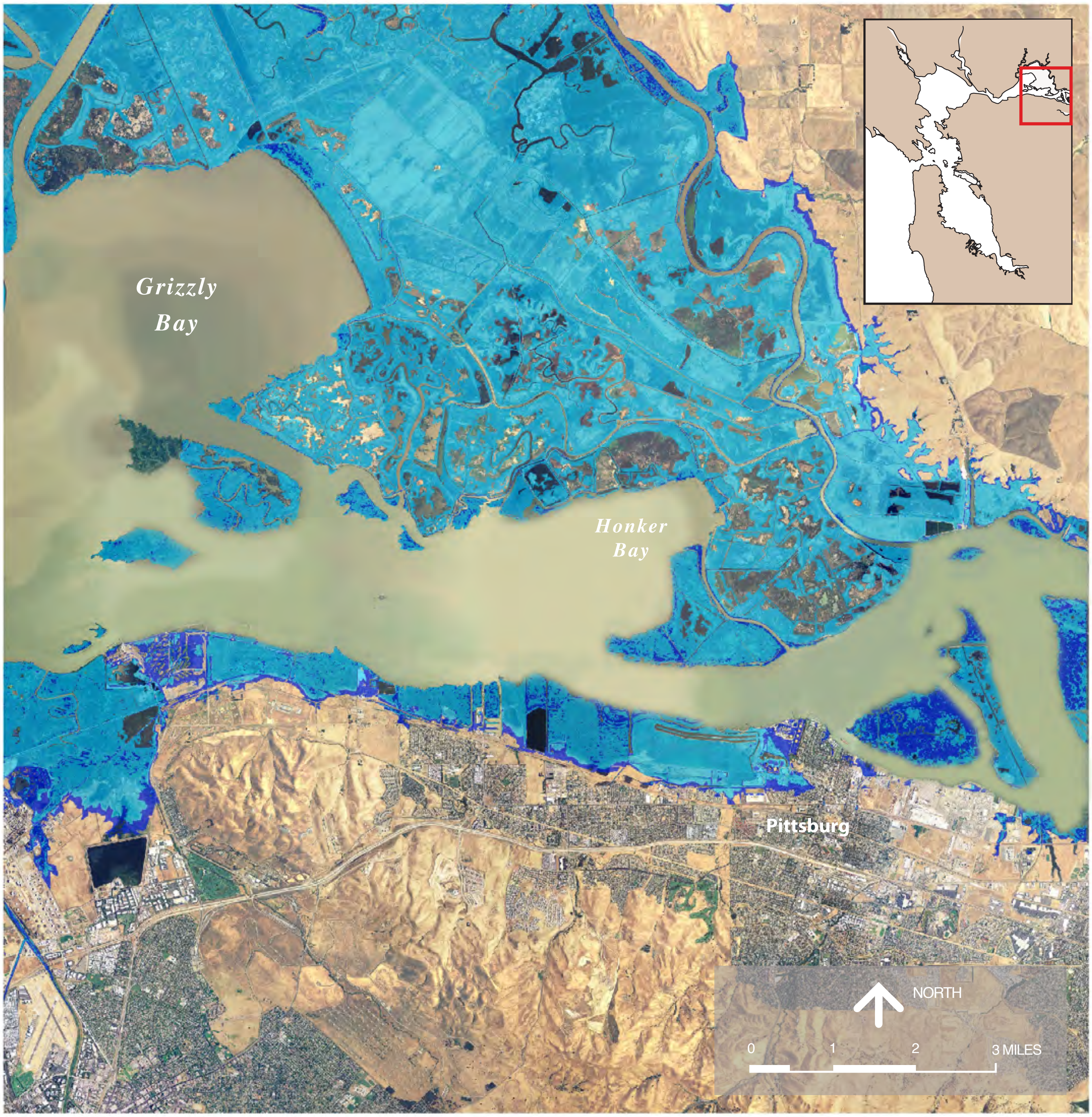

Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

Figure 1.18

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Suisun Marsh
Shoreline Areas Potentially Exposed to Sea Level Rise

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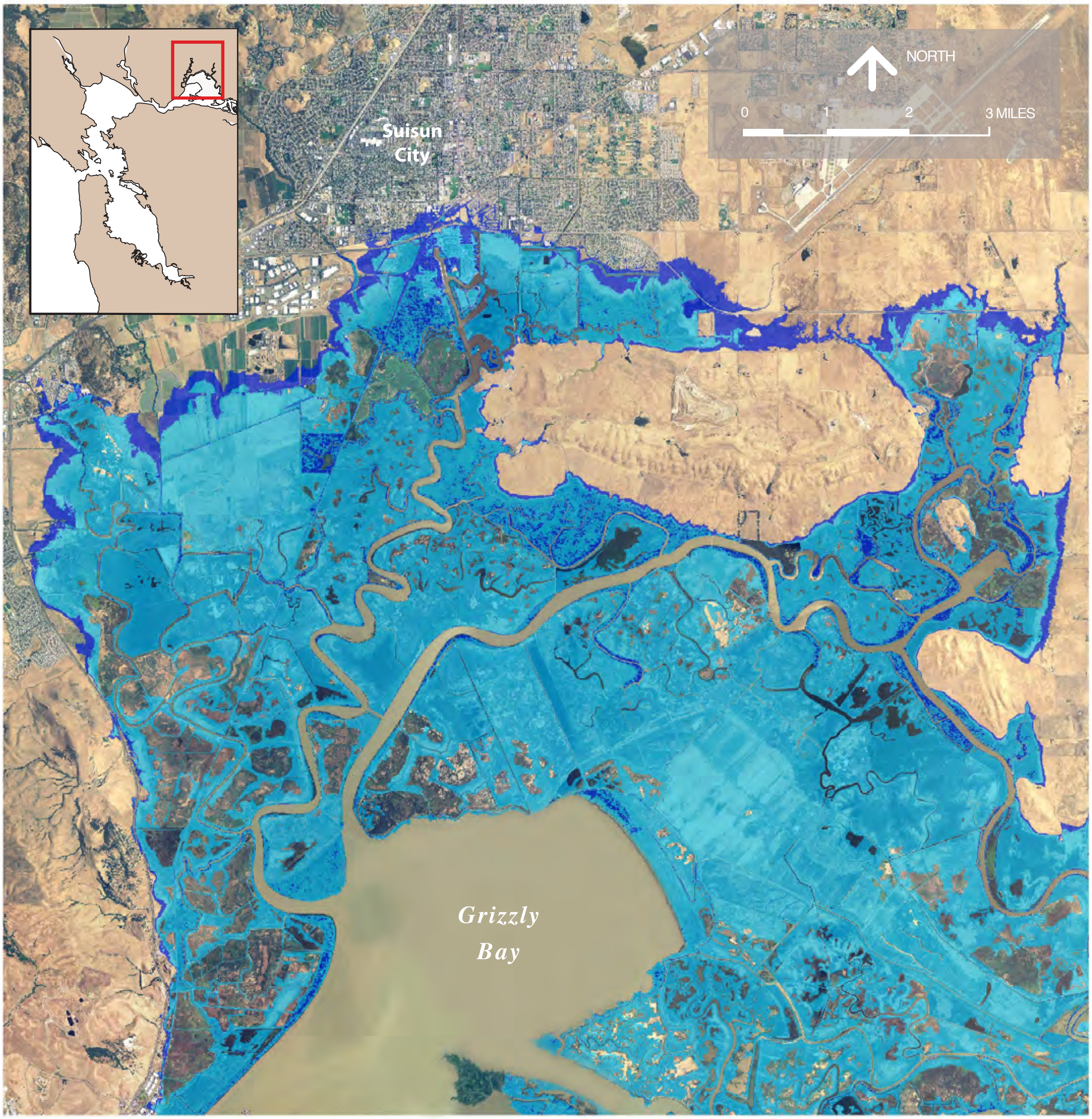

Sea level rise data provided by: USGS science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

San Francisco Bay
Conservation and Development Commission

Figure 1.19

Area potentially exposed to a 100-year high water event

Area potentially exposed to an approximate 16-inch sea level rise

Comparison of Current 100-Year High Water Event and Average High Tide at Mid-Century

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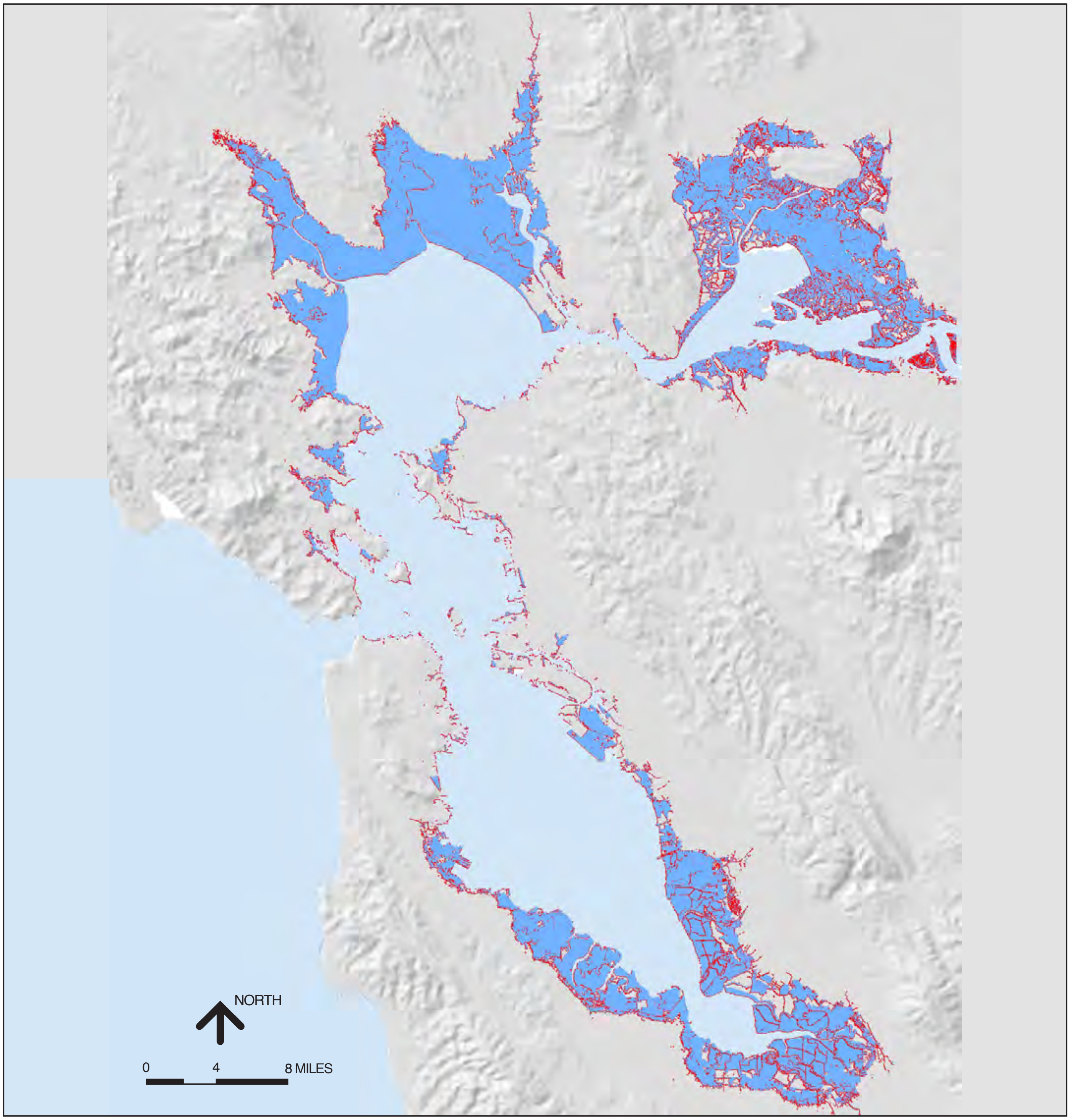


Sea level rise data provided by:
USGS
science for a changing world

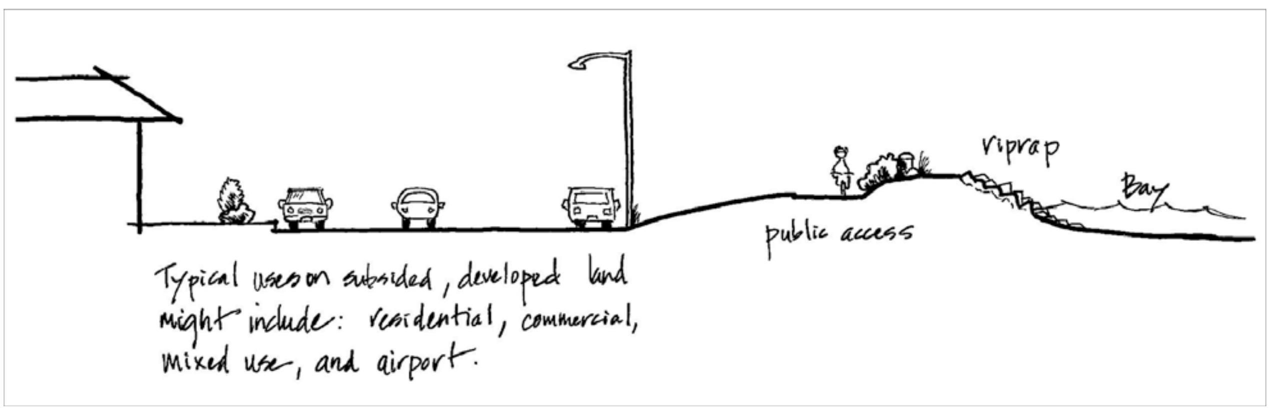
SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002.

Shoreline Protection

San Francisco Bay and the shoreline support some of the densest urban development in the United States as well as ample open space and some of the most extensive tidal wetland habitats (Figure 1.6). Shoreline development, public safety, and the Bay ecosystem are at risk from current flooding and increased future flooding and storm activity. Public infrastructure and shoreline development that are critical to the region's health, safety and welfare will require protection. Wetlands must be sustained to continue providing important habitat and healthy functioning of the Bay ecosystem as well as flood protection and carbon sequestration. A variety of shoreline features and development exist around the Bay, some of which are more vulnerable than others, and all present unique challenges for protection and adaptation to sea level rise[3]. Discovering ways to protect shoreline development and wetlands is one of the major challenges in adapting to future sea level rise.

Figure 1.20 Typical Section: Subsided Land with Structural Shoreline Protection

Source: BCDC



Sea level rise and flooding on the Bay shoreline will lead to a greater risk of erosion, causing local governments and landowners to evaluate protection techniques and strategies. Currently, static structures or structural protection, such as seawalls, riprap revetments and levees, are the most common form of protection against flooding and erosion along the shoreline (Figures 1.20-1.22). Although expensive, these structures are attractive options because the engineering

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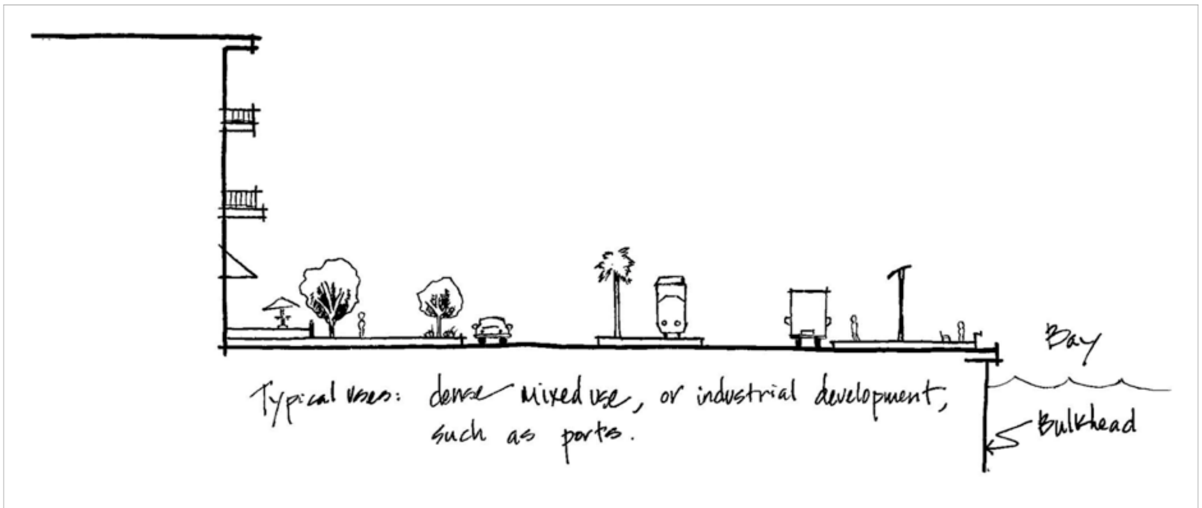
[3] A series of figures showing typical shoreline conditions are included to further an understanding of the variety of shoreline conditions discussed here and in future chapters.

standards for their design and implementation are fully developed and widely used (BCDC 1988a, Smits et al. 2006). Static structures on the edge of a dynamic Bay shoreline can result in erosion of adjacent tidal flats or marshes and eventually the flood protection itself (Williams 2001, Lowe and Williams 2008, Schoellhammer et al. 2005, Smits et al. 2006, Heberger et al. 2008).

Figure 1.21 Typical Section: Urban Shoreline with Bulkhead

Source: BCDC

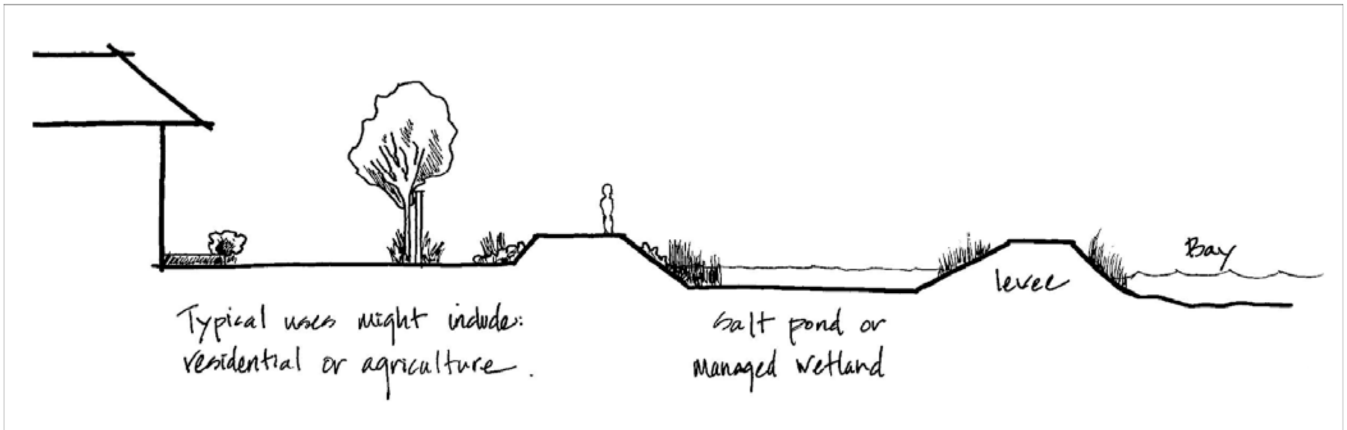


Construction and maintenance of shoreline protection typically requires fill in the Bay (BCDC 1988a). From 1978 to 1987, BCDC authorized nearly 300,000 cubic yards of fill for shoreline protection, most of which was used to construct riprap revetments (BCDC 1988a). Many of these revetments degraded tidal flats that provide important habitat to birds and dissipate wave energy. Thus, residential communities and infrastructure on the shoreline, as well as the Bay ecosystem, may be significantly impacted by the cumulative effect of additional engineered structures along the Bay shoreline to address sea level rise.

Both the construction and maintenance cost of protection structures increases over time, particularly as sea level rises and the damaging effect of storms increases. Since 1990, the construction cost of a waterside levee rose to approximately $1,500 per linear foot, a 320 percent increase, and seawalls are even more expensive at approximately $5,300 per linear foot (Heberger et al. 2008). Maintenance costs range from 1-15 percent of the construction cost per year over the life of the project, which does not include the cost of damages to public safety, infrastructure, or the ecosystem (Heberger et al. 2008).

Figure 1.22 Typical Section: Wetlands and Levees

Source: BCDC



The Pacific Institute reports that statewide the cost of protecting against a 55-inch rise in sea level using static structures would be $14 billion. This cost estimate assumes that, throughout the Bay, levees are sufficient to provide shoreline protection. However, the existing shoreline protection is a mix of levees, riprap and bulkheads or seawalls. Evaluating the full cost of protection measures on the Bay shoreline requires a full assessment of existing structures, both in terms of the level of flood protection and the resistance to erosion under sea level rise projections. In many cases, the wave energy will be sufficient that local governments may desire the additional protection of a seawall, which is far more expensive. Furthermore, Bay levees are constructed, in many cases, using loosely compacted Bay mud that are often insufficient to support the additional weight of material required for retrofitting (URS 2005, PWA 2005). This deficiency is offset, to a degree, because the cost estimate is based on areas potentially exposed to sea level rise and flooding irrespective of whether current protection exists—a more risk-averse approach. Considering that there are multiple types of shoreline protection other than levees, and, that where existing levees cannot be raised, they may require replacement with an alternative method of protection, the Pacific Institute's cost estimate for the Bay is probably low.

Providing structural shoreline protection may actually increase vulnerability by encouraging development in flood-prone areas directly behind the structure and giving those who live behind the structure a false sense of security (Heberger et al. 2008, Smits et al. 2006, United Nations 2004). In areas of the Netherlands, as progressively larger protection structures were built, development behind the structures intensified and populations in those areas increased. The protection structures completely eliminated water circulation in several estuaries, which were ultimately abandoned as functioning ecosystems (Smits et al. 2006). Large areas of the Mississippi Delta are being considered for restoration, in part, to restore previous wave attenuation benefits and help avoid repetition of the devastating impacts caused by Hurricane Katrina, a tragic example of relying too heavily on shoreline protection structures (Day et al. 2007). Loss of this ecosystem benefit is just one of the reasons for ambitious tidal wetland restoration efforts in the Bay-Delta estuary (Save the Bay 2007). While sedimentation and tidal wetlands alone may not completely protect against flooding and erosion (Jongejan 2008), early adaptation of existing development, prevention of new development in flood prone areas, and the flood protection benefit of tidal wetlands can help reduce the cost of adaptation.

The *San Francisco Bay Plan* (Bay Plan) requires a design review process for engineering projects, such as major shoreline protection works on fill. The Bay Plan also includes policies to guide the Commission decisions regarding compensatory mitigation for unavoidable adverse impacts resulting from projects in the Bay. Approving structural shoreline protection on a project-by-project basis may create additional, cumulative adverse impacts to Bay habitat. Analysis of these cumulative impacts and potential planning approaches that will minimize them are needed. Both the USGS and the USACE are currently investigating regional and local effects of shoreline inundation and flooding, respectively, in the South Bay. Additional analysis can provide local governments and landowners with adequate information for designing erosion control and shoreline protection (Knowles 2008, USACE 2008).

Summary and Conclusions

The planet is getting warmer and there is broad scientific consensus that human release of GHGs is driving this change. Greenhouse gases that naturally reside in the earth's atmosphere, absorb heat emitted from the earth's surface and radiate heat back to the surface—a natural process called the "greenhouse effect." The planet is now warming at an accelerated rate due largely to the rapid release greenhouse gases into the atmosphere since industrialization. Temperatures in California are projected to rise between 1.8°F and 5.4°F (1°C and 3°C) by mid century and between 3.6°F and 9°F (2°C and 5°C) by the end of the century. As air temperatures warm, the oceans warm, glaciers and ice sheets melt, causing sea level to rise.

A range of sea level rise projections has been estimated, but they may not adequately reflect future contributions from ice-sheet melt. The estimates for this analysis are based on higher GHG emissions scenarios. Choosing a higher scenario is a more risk-averse approach to protecting public safety. Two sea level rise scenarios were selected for analysis: a 16-inch (40 cm) sea level rise by mid-century and a 55-inch (140 cm) rise in sea level by the end of the century. These scenarios are generally consistent with other state SLR estimates.

Extreme storm events will cause most shoreline damage from flooding. Changes in climate may increase storm activity, which, in combination with higher sea level, will result in more frequent and extensive flooding. The data used for this analysis reflects storm activity, but does not include wave activity. With the 16-inch projection, 180,000 acres (281 square miles) of shoreline are potentially exposed to more flooding or permanent inundation by mid-century and 213,000 acres (332 square miles) are at risk from a 55-inch sea level rise at the end of the century.

Structural shoreline protection can hold floodwaters back from the shoreline. Incorporating both engineering and ecosystem elements can be used to in some cases to mitigate some of the impacts of structural shoreline protection (Lowe and Williams 2008).

Cumulative impacts of structural shoreline protection can have far reaching adverse impacts to the Bay ecosystem. Because structural shoreline protection requires long-term maintenance and can have unintended adverse impacts, it should be seen as only one of several adaptation options for a shoreline area (BCDC 1988a, BCDC 1988b, Smits et al. 2006).

CHAPTER 2
Shoreline Development

Vibrant cities, towns, communities, international airports, critical businesses, research facilities, freeways, railroads, farms, parks, trails and important habitat areas stretch along the shoreline of San Francisco Bay. These shoreline land uses are essential to the region's economy, provide needed housing and jobs for the region's residents, provide habitat for many ecological communities and allow the public to enjoy the Bay. In short, continued, productive use of the shoreline is the cornerstone of the region's prosperity and fosters a strong bond between the region's residents and the Bay.

The nine-county San Francisco Bay Area is home to approximately seven million people, making it the nation's fifth most populous urban center. All nine counties—San Francisco, San Mateo, Santa Clara, Alameda, Contra Costa, Solano, Napa, Sonoma, and Marin—front on the Bay. There are 101 cities within the region and 46 cities situated along the shoreline making the San Francisco Bay one of the world's most urbanized estuaries. The Bay Area's three largest cities are, San Jose (pop. 945,942), San Francisco (pop. 805,235), and Oakland (pop. 390,724) (U.S. Census Bureau, 2010).

The San Francisco Bay Area is one of the most economically productive regions in the nation (Bay Area Council Economic Institute, 2008). The highly skilled workforce is employed in a variety of fields, including health care, technology, information services, finance, education, life sciences, manufacturing and retail. The natural harbor and its proximity to Pacific trading partners allow the region to export more products than most states (Bay Area Council Economic Institute, 2008). The Bay Area is also home to some of the world's leading universities and research institutions making it a key global center for innovation.

If no adaptation measures are taken, an estimated 270,000 people in the Bay Area will be at risk of flooding from a 55-inch rise in sea level—a 98 percent increase over the region's current vulnerability to flooding (Heberger et al. 2009). Shoreline development at risk (buildings and their contents) is estimated at $62 billion—nearly double the estimated cost of sea level rise flood risk along California's Pacific Coast (Heberger et al. 2009). Where lives and property are not directly vulnerable, the secondary and cumulative impacts of sea level rise will affect public health, economic security and quality of life.

Shoreline planners and managers already face challenging issues, such as managing competing land uses, ensuring that shoreline areas are available for water-dependent uses, upgrading aged infrastructure, reducing traffic congestion, protecting habitat and water quality, maintaining flood protection, and providing public shoreline access. In this chapter, shoreline vulnerability is assessed to understand planning and management challenges that may be exacerbated with climate change and identify new challenges that may arise.

Residential Land Use

Land use patterns vary significantly within the region. San Francisco County is the most urbanized with 82 percent of its land developed, while rural Napa County, a highly productive agricultural area, has less than four percent of its land developed. Approximately 16 percent, about 700,000 acres (1,093 square miles), of the region's 4.4 million acres (6,875 square miles) are developed. Over half of this urbanized area is residential and approximately 40 percent contains employment centers, major infrastructure and schools (ABAG 2008). In addition to urban areas, the region has extensive, productive agricultural lands and abundant open space and parks. Within the area potentially exposed to a 55-inch rise in sea level, approximately 51 percent is residential, 32 percent is commercial, and 14 percent is industrial.

Much of the shoreline is former Bay that was filled to create land for housing. Construction of levees along the Bay margin and channeling of creeks and rivers opened up large tracts of land for residential development, most of which is in the current 100-year floodplain. In accordance with the National Flood Insurance Program standards, local governments established elevation requirements for levees, homes, and local roads in floodplains to lessen potential flood risks. However, these standards are based on past flooding events rather than future sea level rise and storm events. Residential development located on subsided land and near the mouth of Bay tributaries—especially at the head of tide where high tide meets tributary outflow—are particularly vulnerable to flooding. One such community is the town of Alviso, in northern San Jose, which is subject to both sources of vulnerability—it has significantly subsided below sea level, sits in close proximity to Alviso Slough, and has suffered periodically from devastating floods. Storm-related flooding also affects some communities in other low-lying and riparian areas, such as Corte Madera and Petaluma.

Difficult choices at the local and regional level are required to determine how to protect housing from future flooding. Approximately 66,000 residential acres (103 square miles) are potentially exposed to a 16-inch sea level rise. Most of this acreage is developed with low-density housing (less than 5 residents per acre). However, 560 acres (0.8 square miles) have over

30 residents per acre and over 5,600 acres (8 square miles) have between 5 and 30 residents per acre. Over 82,000 residential acres (128 square miles) are vulnerable to a 55-inch sea level rise. While most of this area is used for low-density housing, over 1,000 acres (1.5 square miles) contain over 30 residents per acre and over 9,800 acres (15 square miles) contain between 5 and 30 residents per acre (Table 2.1).

Through the JPC, the Commission is a partner in an incentive-based program to focus development near transit and, thereby, reduce driving and GHG emissions. This program, among other important goals, should consider alternatives to siting residences in areas that are vulnerable to flooding (Box 2.1). In consultation with local governments, the FOCUS program has identified Priority Development Areas for infill development in the Bay Area. These Priority Development Areas, along with other sites, are anticipated to be key components of the Bay Area's Sustainable Communities Strategy that will be adopted and periodically updated pursuant to SB 375. One of the Commission's objectives in adopting climate change policies is to facilitate implementation of the Sustainable Communities Strategy. Some shoreline areas that are vulnerable to flooding are already improved with public infrastructure and private development that has regionally significant economic, cultural or social value, and can accommodate infill development. In such cases, the regional goal of concentrating housing and job density near transit conflicts with the goal of minimizing flood risk by avoiding development in low-lying areas vulnerable to flooding. Reconciling these different worthy goals and taking appropriate action requires weighing competing policy considerations and would be best accomplished through a collaborative process involving diverse stakeholders, similar to that being undertaken to develop the Sustainable Communities Strategy.

Table 2.1 Residential Acreage Potentially Exposed to More Flooding or Permanent Inundation with Sea Level Rise

Residential Land Use	Approximate Acreage Exposed to Flooding or Inundation	
	16-inch sea level rise	55-inch sea level rise
Low-density	59,900	72,100
Medium-density	5,600	9,800
Higher-density	560	1,000
Total	66,000	82,000

Source: U.S. Census Bureau 2000.

Box 2.1 The FOCUS Program

FOCUS is a partnership among ABAG, BAAQMD, BCDC, and MTC that encourages future development and growth in areas near existing or planned transit and within existing communities. It is a strategy to work with local and regional entities in the nine-county San Francisco Bay Area by identifying priority development areas (PDAs) that qualify local governments for financial incentives. Priority conservation areas (PCAs) are identified to preserve regionally significant resources, such as agriculture, natural or scenic resources and recreational areas.

PDAs are locally identified, infill development opportunities located within existing communities. They are generally areas of at least 100 acres (0.1 square miles) where there is local commitment to creating more housing in a pedestrian friendly environment that is served by one of the regional transit agencies. The approximately 150 PDAs comprise approximately 106,000 acres (165 square miles) of urban and suburban land. While this constitutes a small percentage of the region's total land area, the proposed areas could accommodate over half of the region's projected housing growth to the year 2035 at relatively modest densities (ABAG website, 2009). Importantly, the increased density around transit can be an effective strategy to reduce greenhouse gas emissions.

Forty PDAs, comprising over 60,000 acres (93 square miles), have a portion of area that is vulnerable to sea level rise. Approximately 2,000 acres (3 square miles) or three percent of the 60,000 acres are vulnerable to a 16-inch sea level rise. Ten percent, or 6,000 acres (9.3 square miles), are vulnerable to a 55-inch sea level rise. It is important to realize that this analysis was conducted with data that identifies the entire extent of the PDA's. It does not necessarily imply that actual development would occur within vulnerable areas. Future efforts should focus on determining the likelihood of secondary impacts upon the identified PDA's, such as impacts to surrounding transportation infrastructure. Appropriate adaptation strategies should be developed for any vulnerable site (Figures 2.1- 2.2).

Residents with Increased Vulnerability. One definition of a resilient community is a community that "takes intentional action to enhance the personal and collective capacity of its citizens and institutions to respond to, and influence the course of social and economic change" (CCE 2000). A critical characteristic that enables communities to respond to and influence social and economic change is their current economic security, because it adds to their overall feeling of safety and security (Coburn 2008). Other attributes of resilient communities, such as active participation in democracy, willingness to draw on resources within the community, or confidence (Coburn 2008) may be compromised by a lack of economic security. For example, a low-income community may have a willingness to draw on resources within the community, but several of the essential resources on which to draw are missing: money being the obvious resource; or time spent working and commuting that might otherwise be available as a resource.

A number of low-income communities on the Bay shoreline are potentially exposed to sea level rise. A disproportionate number of low-income residents are potentially exposed to a 55-inch rise in sea level in five Bay Area counties: Contra Costa, Solano, Sonoma, Marin, and Napa (Heberger et al. 2009)[1].

[1] This information comes from a statewide study of coastal and Bay shoreline impacts. Marin and Sonoma Counties may or may not have greater proportions of low-income residents on the coast or Bay shoreline. Furthermore, because the study applies statewide, a lower percentage was used in the calculation of low-income that may exclude some Bay Area residents (see "5" below).

A low-income community is an area where 30 percent or more of the households earn less than 200 percent of the national poverty threshold.[2] Low-income communities are less likely to have sufficient resources to rebuild housing after a flood or to relocate. The canal district in San Rafael (Figure 2.3) is an example of a predominantly low-income community that is highly vulnerable to flooding.

Low-income communities are likely to be less resilient to the indirect, cumulative impacts of climate change and adaptation efforts. For example, a 16-inch sea level rise will only reach the margins of low-income neighborhoods in Redwood City, East Menlo Park and East Palo Alto (Figure 2.4). However, critical transportation infrastructure that traverse these areas—Highway 101 and the entrances to the Dumbarton Bridge, and Caltrain railroad—will likely be significantly affected by sea level rise. Retrofitting this essential transportation infrastructure could have direct impacts on these neighborhoods. For instance, construction activity on transportation infrastructure can change or disrupt access to public transportation, local shopping, jobs, or medical centers. Easy access to such facilities is something that an automobile owner or an individual with more flexibility in their work schedule takes for granted. On a regional level, the impacts from disruption of services would be offset by the benefits from retrofitting important highways and rail corridors. Low-income households may have fewer resources or alternatives available to withstand interim impacts.

A recent report by the California Climate Change Center estimates that 150,000 Asian, black and Latino residents live in areas at risk of a 100-year flood event along the Bay with a 1.4-meter rise in sea levels (Heberger et al. 2009), and confirms that "along the San Francisco Bay…communities of color are disproportionately impacted by sea-level rise" (Heberger et al. 2009). Bay Area counties with populations that disproportionately include people of color vulnerable to sea level rise, compared to the county as a whole, are Contra Costa, Marin, Solano, Napa, Sonoma, Alameda and San Mateo (Heberger et al. 2009). The report concludes that "the greater proportion of people of color in areas affected by a 1.4-meter sea-level rise highlights the need for these counties to take concerted efforts to understand and mitigate potential environmental injustice" (Heberger et al. 2009).

[2] These thresholds are maintained by the U.S. Census Bureau and are scaled based on size and age of a household. Two hundred percent of the national poverty threshold is the standard equation used by other Bay Area agencies to represent low-income based on the standard of living requirements in the Bay Area.

In such communities, it is especially important to take proactive measures to prevent harm and reduce vulnerabilities, such as reinforcing residential buildings, obtaining insurance, storing emergencies supplies, and having access to transportation, evacuation services and emergency medical care. This may be particularly difficult in areas with high concentrations of rental housing and low English-speaking populations. In areas potentially exposed to sea level rise along the Bay, there are currently 47,000 rental households and 9,700 "linguistically isolated" households (meaning no one over the age of 14 speaks fluent English, (Heberger et al. 2009). People of color in California also live disproportionately near (within 3 kilometers) hazardous waste facilities (Heberger et al. 2009). It is estimated that 130 EPA-regulated sites that contain hazardous wastes are currently potentially exposed to a 100-year flood event in San Francisco Bay; the number of facilities at risk increases to 330 with a 1.4-meter rise in sea levels (Heberger et al. 2009). Additional studies are needed to determine where vulnerable populations are located in proximity to these and other sites with hazardous or toxic substances. The California Climate Change Center notes, "what we choose to protect and how we pay for it may have a disproportionate impact on low-income neighborhoods and communities of color" (Heberger et al. 2009).

Some residents are more vulnerable to sea level rise because it would be physically difficult to evacuate in the case of an emergency flood situation or more difficult to relocate if special facilities are required. People with disabilities, the elderly, or those who are already ill may experience these difficulties. Children will also have greater difficulty evacuating, requiring the assistance of their parents. Single parents may face particular difficulty helping children evacuate or relocating to a new home. Additionally, these populations are more vulnerable to a drop in economic status, which could subject them to the additional vulnerabilities faced by low-income residents. Additional research is necessary to develop more information on the potential impacts to particularly vulnerable populations and to develop quantitative data on their vulnerability to future flooding. This should be a high regional priority.

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Figure 2.1

Area potentially exposed to an approximate 16-inch sea level rise
Area potentially exposed to an approximate 55-inch sea level rise
No data
Priority Development Area — Major Roads and Highways

South Bay
Priority Development Areas
Potentially Exposed to Sea Level Rise

0 1 2 3 MILES NORTH

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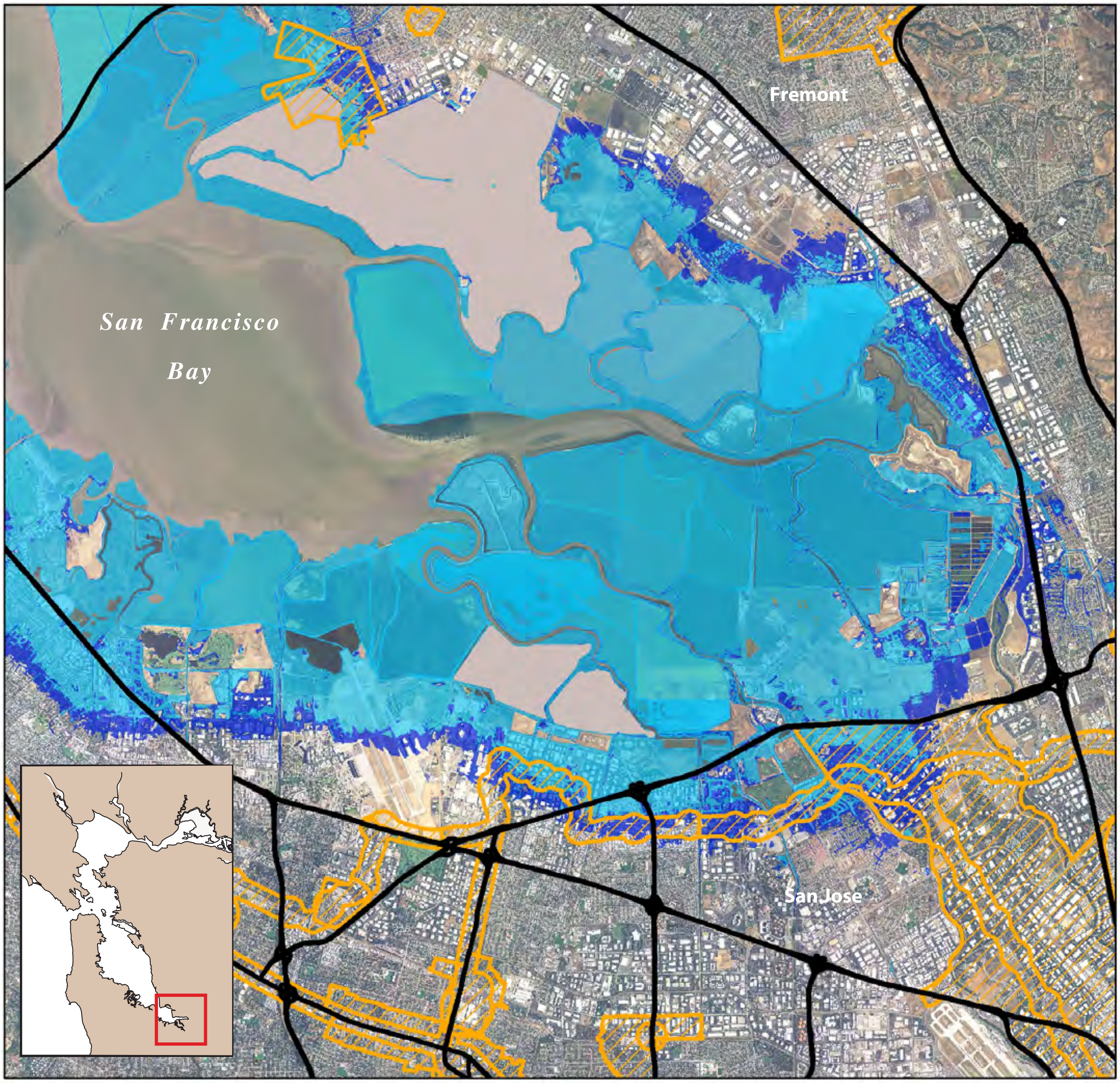

Sea level rise data provided by: USGS science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; ABAG, 2008.

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

No data

Priority Development Area

Major Roads and Highways

Central Bay North
Priority Development Areas
Potentially Exposed to Sea Level Rise

0 1 2 3 MILES

NORTH

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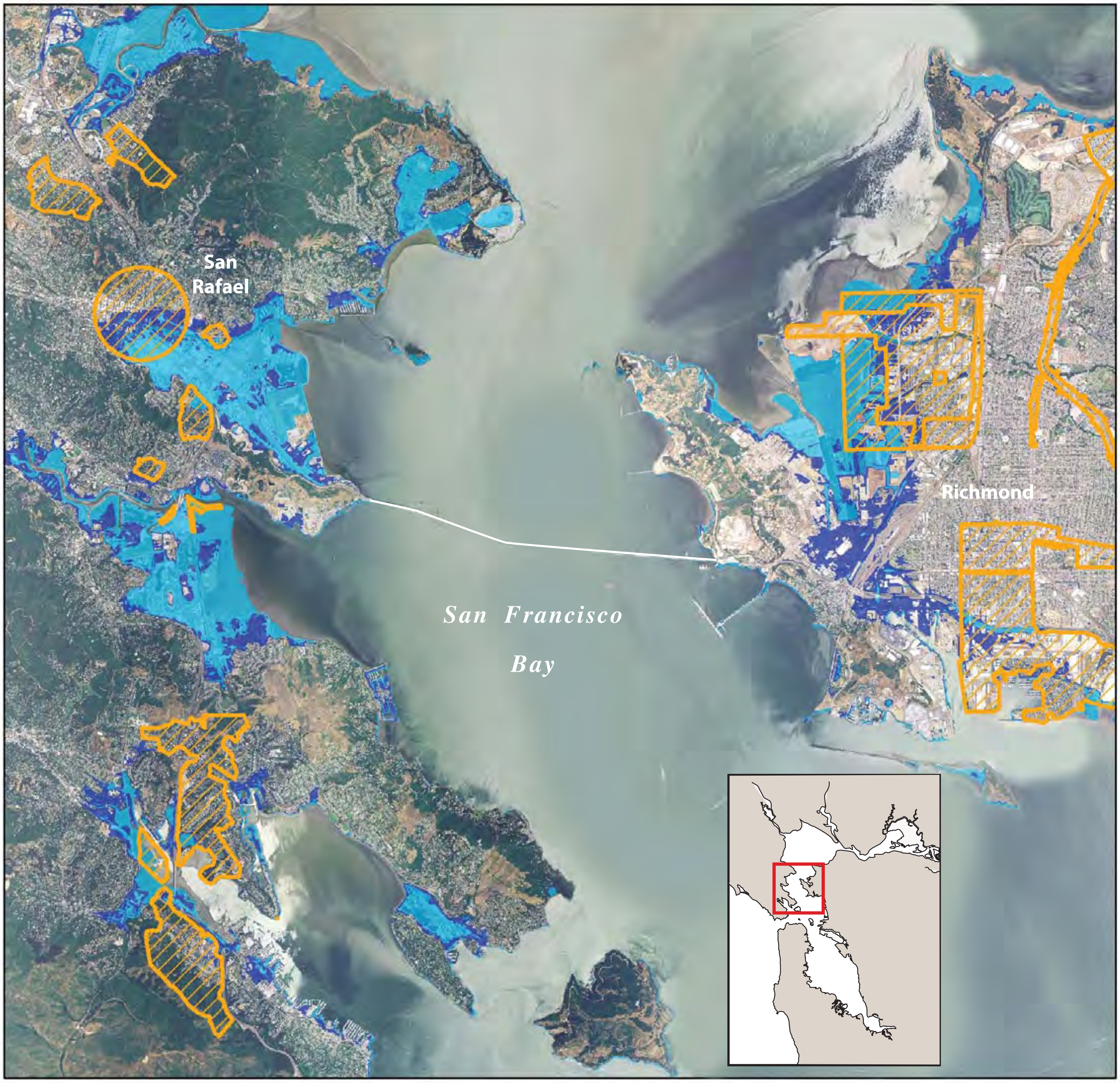

Sea level rise data provided by:

USGS science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; ABAG ,2008.

Central Bay North Low Income Residential Areas Potentially Exposed To Sea Level Rise

30% or more of the households below Federal Poverty Level

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Major roads and highways

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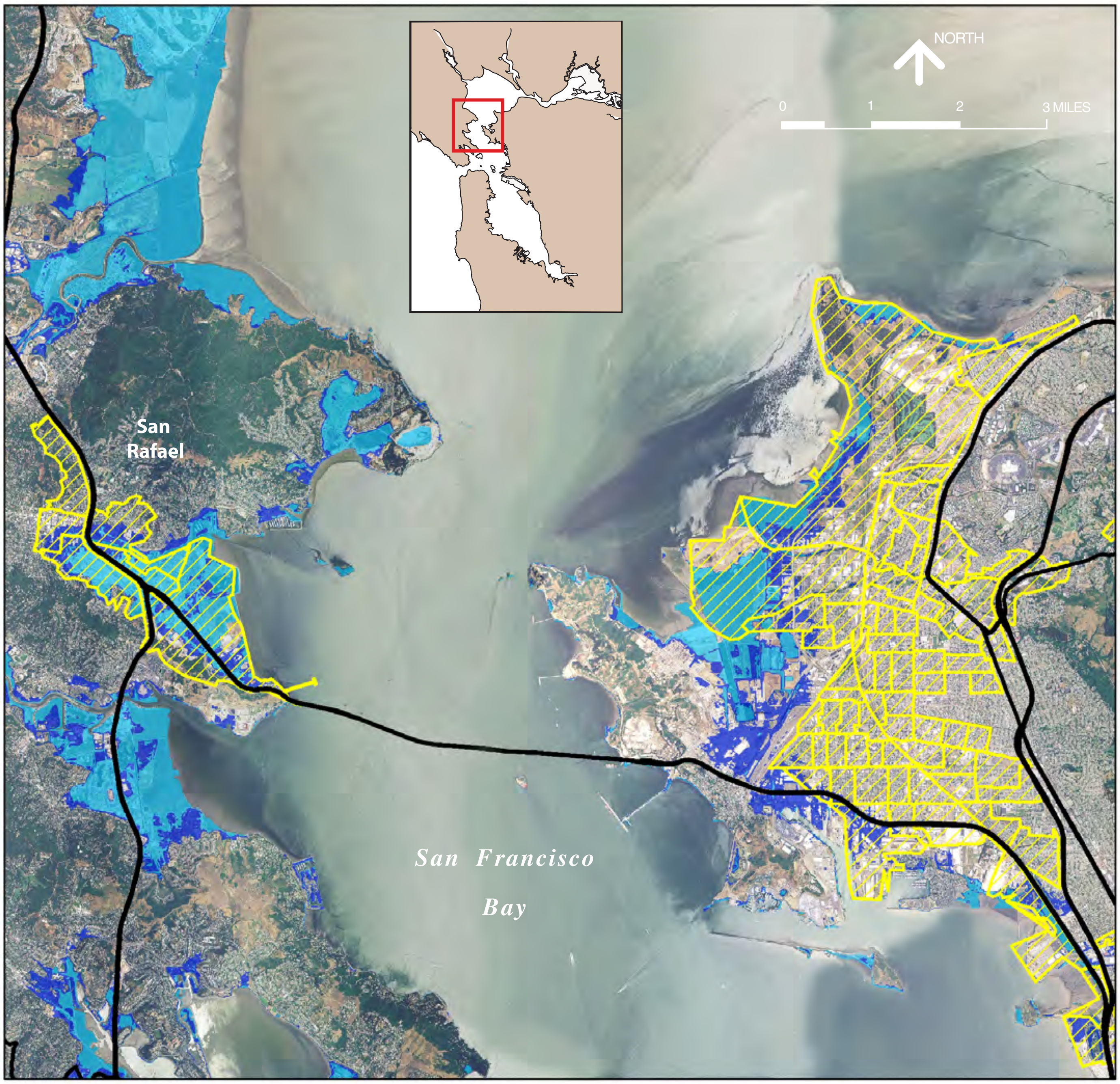

Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; Census Bureau, 2000.

San Francisco Bay
Conservation and Development Commission

Figure 2.4

30% or more of the households below Federal Poverty Level

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Major roads and highways

Central Bay South Low Income Residential Areas Potentially Exposed To Sea Level Rise

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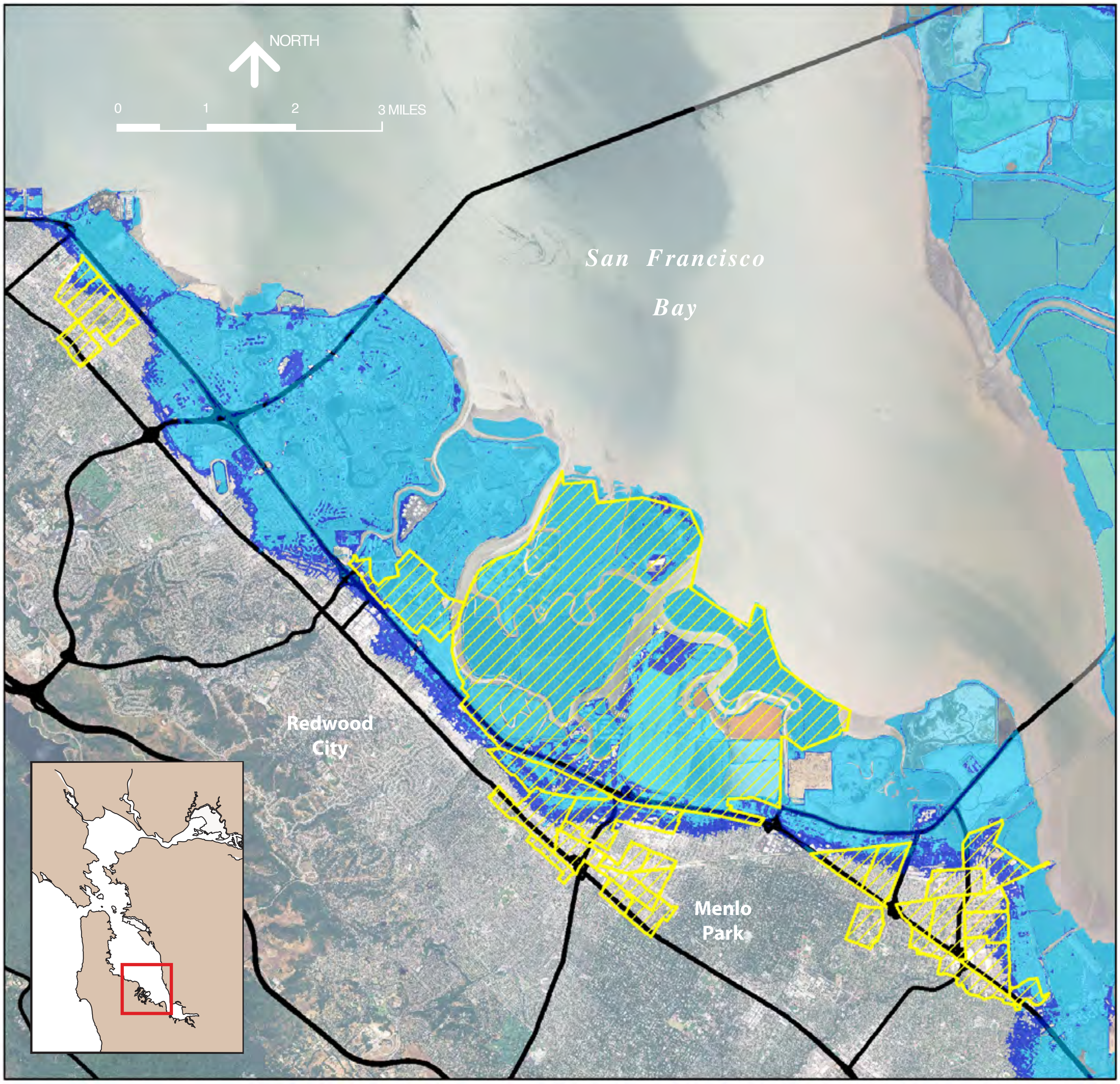

Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; Census Bureau, 2000.

Schools and Emergency Services. Important civic institutions such as schools, fire stations and hospitals are at increased risk of flooding under both sea level rise scenarios. Thirty-five schools are located in the current 100-year flood plain—where the risk of flooding increases substantially by mid-century. That number increases to 81 with 55-inches of sea level rise (Heberger et al. 2009). Eleven fire stations, nine police stations, and 42 healthcare facilities are potentially exposed to flooding or permanent inundation with 55-inches of sea level rise (Heberger et al. 2009). The extent to which this could compromise emergency response in an extreme event requires additional attention in coordination with the Federal Emergency Management Agency, cities and counties.

Commercial and Industrial Land Use

In 1969, when the Legislature adopted the Bay Plan into law, it recognized that some regionally significant land uses require a shoreline location. Without protecting shoreline areas for these land uses, there would be future pressure to fill the Bay to accommodate them. Therefore, the Bay Plan designates areas of the shoreline that are suitable for water-oriented priority uses: airports, ports, water-related industry, wildlife refuges and waterfront parks and beaches. Currently there are 86 designated areas comprising over 167,000 acres (260 square miles) throughout the nine-county region. These priority use areas help make the Bay Area one of the most economically prosperous, ecologically rich and healthy urban centers in the world and they all will experience some increase in potential exposure to flooding.

Airports. Two international airports in the region, San Francisco International (SFO) and Oakland International (OAK) are located on the Bay shoreline. These two airports provide important linkages with international and domestic trading partners and serve as major hubs of the national and global air passenger system and air cargo network.

SFO is the principal international air passenger gateway within the region. In 2010, SFO was the ninth busiest airport in the country at over 39 million passengers, up from 36 million passengers in 2007 (Airports Council International-North America 2010). In 2010, SFO also handled 427,000 metric tons of cargo, down from 563,000 metric tons in 2007 (ACI-NA 2010). In 2010, OAK handled approximately 9.9 million passengers, down from 14.8 million passengers in 2007 (ACI-NA 2010). Additionally, OAK handled roughly 511,000 metric tons of cargo in 2010, down from 648,000 metric tons in 2007 (ACI-NA 2010). Air cargo is the fastest growing segment of the goods movement economy and is forecast to triple in the next twenty to thirty years (MTC, 2004).

Both airports have limited land available for expansion of passenger and cargo facilities and runways. Funding for such improvements is limited due to federal budget constraints and the deteriorating financial health of national airlines. The two airports cover approximately 4,700 acres (7.3 square miles) along the shoreline of the Bay. Without any shoreline protection, over 3,400 acres (five square miles) or 72 percent of these designated lands would be potentially exposed to a 16-inch sea level rise while approximately 4,400 acres (six square miles) or 93 percent of these designated lands would be potentially exposed to a 55-inch sea level rise (Figure 2.5).

At OAK, the perimeter dike serves as the flood protection system for the airport's South Field, including the main air carrier runway and passenger terminal facilities. The dike was constructed using dredged bay mud, sand, and gravel during the 1950s to 1970s. Two active fuel lines are buried under the dike crest. As part of its Airport Perimeter Dike Improvement Project, the Port of Oakland plans to construct improvements to the dike, portions of which currently do not meet FEMA 100-year flood protection standards (Port of Oakland, 2011). The Port estimates that the dike system protecting OAK can currently support approximately 36 inches of sea level rise at mean higher high water. Proposed dike improvements include, where necessary, raising the height of the dike, stabilizing inboard slopes, protecting against seepage, and strengthening portions of the dike that are vulnerable to seismically-induced liquefaction.

SFO was built on landfill and has addressed runway subsidence through a regular program of repaving and overlay. A partial seawall protects the runways and reduces their exposure to flooding. In order to address the gaps remaining in the existing shoreline protection system, SFO has been coordinating with FEMA to certify its seawalls and update flood maps. SFO is investigating the issue of storm surge to determine whether additional seawall or levee heights are needed and whether existing drainage is sufficient. As sea level rises, raising levees or other adaptation measures will be necessary to protect runways from flooding. Detailed vulnerability assessments for the airports will need to consider existing shoreline protection, extreme tides, storm surge, wind-driven wave run up and other factors.

Congestion within the highway networks that serve each airport makes airport access difficult for passengers and cargo distributors. SFO is linked to the highway transportation network via the U.S. 101 and also has direct Bay Area Rapid Transit (BART) passenger service. Segments of the U.S. 101 and the BART tracks near the airport are potentially exposed to a 16-inch sea level rise. OAK is linked to the region via the I-880 corridor, which is vulnerable to flooding near Port of Oakland and the Bay Bridge approach (Figure 2.6).

The Regional Airport Planning Committee—a collaborative effort between BCDC, the Metropolitan Transportation Commission and the Association of Bay Area Governments—was formed to address regional airport planning issues. During its recent update to the Regional Airport Systems Plan Analysis, the committee analyzed methods to reduce GHG emissions from airports and address the affects of future sea level rise.

Ports. There are five major ports in the Bay Area located at Oakland, Richmond, San Francisco, Redwood City and Benicia. Like the region's airports, the ports rely on the transportation network to move cargo and employees to and from the ports. The ports handle a variety of cargo types, including container cargo, dry bulk, break bulk, neo bulk and liquid bulk. Maritime cargo handled by these five ports was 19,114,199 metric tons in 2010, a 58 percent increase since 1994 (BCDC 2011). The Port of Oakland (Port), the nation's fifth busiest container port, handles the largest volume of cargo within the region and currently exports more cargo than it imports. In 2010, the Port handled over 2.3 million twenty-foot equivalent units (TEUs; a standardized size of the containers in which goods are shipped) (Port of Oakland 2011). The port generates over 28,800 direct, indirect, and induced jobs in the Bay Area, and an estimated 444,000 jobs in California are in some way related to the Port's activity (Martin Associates 2011). The Port was estimated to generate $3.7 billion annually for the regional economy in 2008 (MTC 2008). However, containerized trade declined sharply in 2008 and 2009 due to the recession (The Tioga Group 2009).

Commercial, residential, port, and other industrial uses compete for highly desirable shoreline property.[3] Port activities are normally inconsistent with commercial and residential uses and raise concerns over public health and noise. Constituencies are created that may oppose port improvements or expansion due to this perception. However, ports serve an important economic function and require shoreline locations. In addition to occupying waterfront sites, ports require maintenance activities that can impact the Bay: maintaining deep-water channels and berths through dredging for the movement of large vessels is not compatible with growth of estuarine ecological communities.

[3] Most of the property on which the Port of Oakland's marine terminals and other facilities are located is subject to the terms of State of California tideland trust grants, which generally limit land uses to harbor and airport uses and other uses of statewide interest, such as fishing, public recreation, and enjoyment of the waterfront.

San Francisco Bay Conservation and Development Commission

Figure 2.5

Central Bay West Shore Transportation Network and Shoreline Priority Use Areas Potentially Exposed to Sea Level Rise

- Area potentially exposed to an approximate 16-inch sea level rise
- Area potentially exposed to an approximate 55-inch sea level rise
- Port and Water-Related Industry
- Airport
- Waterfront Park, Beach
- Major Roads and Highways
- BART
- Railroad

DISCLAIMER: *Inundation data does not account for existing shoreline protection or wave activity. These maps are for informational purposes only. Users agree to hold harmless and blameless the State of California and its representatives and its agents for any liability associated with the use of the maps. The maps and data shall not be used to assess actual coastal hazards,insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by the Federal Emergency Management Agency (FEMA).*

Sea level rise data provided by: USGS science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; BCDC, 2009; MTC, 2009.

San Francisco Bay Conservation and Development Commission

Figure 2.6

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Port and Water-Related Industry

Airport

Waterfront Park, Beach

Major Roads and Highways

BART

Railroad

Central Bay Transportation Network and Shoreline Priority Use Areas Potentially Exposed to Sea Level Rise

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Sea level rise data provided by: USGS science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; BCDC, 2009; MTC, 2009.

Shoreline flooding and damage to Bay Area ports as a result of sea level rise would likely have a ripple effect through much of the west coast economy. All of the region's ports are vulnerable in varying degrees to projected sea level rise. Collectively, 2,700 acres (four square miles) of land is designated for port use. Approximately 100 acres (0.16 square miles) or four percent of land within the port areas are potentially exposed to a 16-inch sea level rise while approximately 500 acres (0.78 square miles) or 20 percent of land within the port areas are potentially exposed to a 55-inch sea level rise. Additionally, segments of the ground transportation network that make vital connections to the Port of Oakland are at greater risk of flooding (Figure 2.6). Several vulnerabilities exist in the Central Corridor, the major trade route in the region, which originates at the Port of Oakland, runs roughly parallel with I-80, and heads toward Sacramento and beyond.

Water-Related Industry. Water-related industries are those that require shoreline locations to receive and process raw materials and distribute finished products via deep water shipping lanes, rail corridors or highways. For example, water-related industrial operations include chemical and petroleum refining and storage, metal refining and fabrication, food processing, mineral resource processing and dredge material handling facilities.

The costs of doing business in the Bay Area rank among the highest in the nation. These high costs combined with other changes to the region's economy have driven many manufacturing jobs out of the region, resulting in a job loss of 11 percent since 1995 (Bay Area Economic Forum, 2004). Additional factors that have compromised the competitive advantage of Bay Area industries include, globalization, technology-driven improvements in productivity, a shift away from a manufacturing-based economy towards a service-based economy, as well as demographic shifts (Bay Area Economic Forum, 2004). Like ports and airports, water-related industries occupy desirable shoreline property that is subject to encroachment of mixed-use and residential land use into adjacent areas. Several communities have expressed interest in redeveloping water-related industrial sites with non-industrial development, continuing a trend that has been underway in the region for decades.

Collectively, designated water-related industrial lands cover approximately 12,350 acres (19 square miles). Approximately, 2,000 acres (3 square miles) or 16 percent of these designated areas are potentially exposed to a 16-inch sea level rise while approximately 3,500 acres (5 square miles) or 28 percent of these designated areas are potentially exposed to a 55-inch sea level rise. Future flooding could disrupt the operations of water-related industries and, thus, the provision of important resources to the region. For example, many of the petroleum refineries provide fuel for the region's airports, goods movement and commuters.

Table 2.2. Summary of Land Use Acreages Potentially Exposed to Flooding or Permanent Inundation from Sea Level Rise

Land Use	Existing Area (acres)	Acreage Exposed to Sea Level Rise	
		16 inches	55 inches
Airports	4,700	3,400	4,400
Ports	2,700	100	500
Water-related Industry	12,350	2,000	3,500
Total	19,750	5,500	8,400

Indirect Effects of Sea Level Rise

In addition to the direct effects of sea level rise, such as increased flooding, sea level rise can be expected to have indirect impacts on groundwater. Sea level rise is expected to lead to salinity intrusion into groundwater along the shoreline, potentially impacting shoreline wells and shifting the coastal vegetation to more salt-tolerant species. Sea level rise will also raise the water table along the shoreline, increasing the risk of flooding by limiting the amount of precipitation that can infiltrate the ground. A higher water table will also increase the risk of soil liquefaction during an earthquake (Holzer 2006).

Public Health Impacts of Climate Change

Sea level rise is just one of many potential impacts of climate change on the San Francisco Bay region. Climate change is likely to impact public health in the region by changing conditions such as air quality, heat events, water quality and the distribution of vectors and infectious diseases. The populations most vulnerable to impacts include those who are already ill, people with disabilities, children, the elderly and the poor (Luers et al. 2006). The state currently experiences the worst air quality in the nation and over 90 percent of the population lives in areas that exceed either the ozone or particulate matter air quality standards. Ozone and particulate matter combined, contribute to over 8,800 deaths and $71 billion in health related costs per year (Luers et al. 2006). Higher temperatures will exacerbate air pollution by increasing the frequency, duration and intensity of conditions that lead to air pollution formation. Other factors such as wildfires contribute to unhealthy air quality conditions. In the summer of 2008, regional air quality was directly impacted by wildfires, which are expected to increase in frequency under climate change conditions.

Heat events are also likely to be more intense, last longer and occur earlier in the year relative to historical events (1961-1990) (Dreschler et al. 2005). Higher temperatures can lead to increased risk of heat-related illnesses (heat exhaustion, dehydration, heat stroke and respiratory distress) or mortality, particularly among the most vulnerable populations, such as the elderly, young children and people with chronic illnesses.

Water quality impacts on the Bay can affect Bay Area residents. Marine processes that affect the Bay ecosystem (Chapter 3) are impacted by temperature increases and sea level rise, which can kill phytoplankton, alter fresh and salt water mixing and upwelling, and disrupt primary productivity. Impacts upon these processes could lead to algal blooms and hypoxia, which could impact water quality.

Other public health impacts could include the potential for expansion of the range of infectious diseases and vectors as a result of changing environmental conditions. Vector borne disease may become a public health concern as the life cycles of organisms such as mosquitoes, ticks, fleas and rodents change as a result of climate change. Waterborne disease occurrences linked to storm runoff from heavy rainfall, flooding, and sewage overflow could become a health concern (Dreschler et al. 2005). However, predicting the impacts of vector borne diseases is challenging due to the multiple interactions between climate, host and vector organism, vector control programs and public response to control programs.

Other Shoreline Land Uses, Infrastructure and Institutions

Beyond the land uses that have been discussed above, there are other regionally important, non-recreational shoreline land uses, infrastructure, and institutions that may be vulnerable to future coastal flooding. These include water and sewage treatment plants, flood control channels, landfills, contaminated sites, pipelines, power transmission lines, schools, fire stations and hospitals.

Wastewater Treatment Facilities. Most of the Bay Area's water and sewage treatment facilities treat wastewater and sewage that is discharged in the Bay. There are 22 wastewater treatment plants on the shoreline that are vulnerable to a 55-inch rise in sea level (Heberger et al. 2009), many of which lack the capacity to handle current storm flows resulting in frequent sewage spills. Without modifying these facilities, more frequent storms associated with sea level rise will increase the number of spills in the Bay. Many treatment plants rely on gravity to discharge treated water into the Bay. As Bay water levels rise, this mechanism could fail and significantly impact facility operations. Flooding of treatment facilities can disrupt operations or damage pumps and related machinery. Should Bay waters exceed the elevation of plant intake structures, saltwater intrusion into treatment facilities will alter biotic conditions necessary for the breakdown of waste material. Sea level rise will likely require significant investments to retrofit or relocate some sewage treatment plants. Although the Commission's law requires that new fill, such as intake structures, must minimize impacts to water quality, the San Francisco Bay Regional Water Quality Control Board has primary authority over water quality in the Bay.

Flood Control Channels. In addition to the rivers and creeks that feed the bay, there are a number of flood control channels that drain upland areas. Sea level rise and potential changes in the precipitation patterns may alter the flow dynamics of these channels. With higher Bay water levels and more extreme storm events, Bay water will intrude further into flood control channels making it more difficult for fresh water to drain rapidly from upland areas. This will increase flood risks in locations further upstream. More precise identification of upland areas near creeks and flood channels where this type of flooding may occur is needed for addressing future flood risks. Exploring alternative methods of flood control may be necessary.

Contaminated Lands. Prior to BCDC's creation, many municipalities filled the Bay for disposal of garbage and waste materials. These landfills contain contaminants and toxins. Some are still in operation while others have reached capacity, have been closed and converted to other shoreline land uses, such as waterfront parks. Higher sea levels and extreme storm events will cause flooding and erosion, or raise ground water levels that may impact the integrity of shoreline landfills and release contaminated leachate, adversely impacting ecosystems and public health.

In addition, there are a number of shoreline areas that contain contaminated land as a result of past industrial, commercial or military uses that were more common along the shoreline over the past century. For example, many of the retired shoreline military sites contain contaminated lands that have yet to be fully remediated. Many sites have been remediated with their wastes encapsulated onsite, under the assumption that they would remain upland and dry. If these sites become flooded, subject to groundwater intrusion or eroded, they could release contaminants. While extensive and ongoing efforts have been made to remediate contaminated sites around the Bay, it will be imperative to address this issue before contaminated sites begin to be impacted by sea level rise.

Pipelines and Transmission Lines. Numerous pipelines and power transmission lines cross under the Bay, cut across wetlands, and parallel the shoreline, distributing water, petroleum and energy. Transmission towers sit on footings within the Bay, which must be constructed at elevations so that towers are either above high tide or can withstand increased exposure to corrosive salt water. The footings must also be engineered keep towers standing through extreme storm events.

Pipelines carry petroleum products across important wetlands, including the Suisun Marsh—one of the largest habitats on the Pacific Flyway, which is at great risk of flooding under both the 16-inch and 55-inch scenarios. In 2004, a 14-inch-in-diameter pipeline ruptured and discharged 123,774 gallons of diesel fuel oil into the marsh damaging approximately 224 acres (0.3 square miles) and injuring a variety of birds, small mammals, fish, reptiles, and aquatic and terrestrial invertebrates (Kinder Morgan 2008). The California Department of Fish and Game's Office of Oil Spill Prevention and Response (OSPR) was instrumental in containing the spill. To prevent future pipeline spills that could be caused by rising sea level, OSPR and regulatory agencies must ensure that pipelines traversing the Bay, wetlands, and vulnerable uplands are retrofitted to withstand higher water levels or relocated.

The Regional Transportation Network

The Bay Area relies heavily upon its transportation network. Central to the quality of life enjoyed by residents and the region's overall economic prosperity, is an interconnected network of railroads, major roads and highways, BART, ferries and bicycle lanes. These transportation elements allow for the movement of goods within the region and with domestic and international trading partners, while providing mobility to residents by getting them from their houses to their jobs, families, friends and to recreational areas. Residents travel within the region by a variety of modes. In 2000, 83 percent of all trips within the region were made by auto, 10 percent by walking, 5 percent by transit and 2 percent by bicycle (MTC staff, 2009).

Transportation-dependent industries, such as ports and airports, employ almost half of the workers in the region. Goods-producing businesses spent approximately $8.6 billion on transportation in 2000 (MTC, 2004). The major roads and highways and rail network serve to link the regional ports and airports with inland markets including the important Central Valley agricultural economy. Projections for goods movement within the Central Corridor indicate that by 2016 goods movement along the corridor is projected to grow to approximately 90 million tons and will be valued at $101 billion (TCIF/MTC, 2008).

The transportation network also provides mobility to residents and includes the Bay Area Rapid Transit (BART) system, the regional rail and ferry network, sidewalks, trails, and a regional bike network. The BART system spans 104 miles, contains 43 stations and carries an average of 357,000 riders every week (BART, 2008). Passenger rail service is provided by a number of operators including Amtrak, Altamont Commuter Express (ACE) and Caltrain. Ferry service is provided by the Golden Gate Highway Transportation District, Blue and Gold Fleet, Vallejo Baylink, and Harbor Bay Maritime. As of 2001, annual ferry ridership exceeded over 4,000,000 passengers and has been steadily increasing in the last decade (WTA, 2003). Bicycling within the region has also been increasing and a network of bike lanes is being linked to the public transportation network. Certain Bay Area cities have higher percentages of bike ridership including, Berkeley (4.9 percent) and Palo Alto (5.8 percent), when compared with the rest of the nation (0.1 percent) (U.S Census Bureau 2000 and MTC, 2001).

Major Roadways and Highways. Although the Bay is an essential part of life in the Bay Area, it is sometimes viewed an impediment to the mobility of goods (BCDC, 2005), requiring bridges to cross its water and long stretches of highway to traverse the shoreline. Trucks move most goods within the region, making major roads and highways a critical component of the goods movement network. This network supports local businesses that require delivery of supplies for production and finished products to consumers. Goods producing industries contribute $213 billion to the regional economy and account for 37 percent of the region's industrial output (MTC, 2004). Many of the major nodes of the goods movement network, such as ports and airports, are situated on the shoreline and are connected to producers and consumers via the road network. Four primary road corridors, I-880, I-580, I-80 and U.S. 101 handle 80 percent of the goods movement within the region. These roadways serve to link the major economic centers of the region, including San Francisco, Oakland, San Jose and Silicon Valley, thus providing mobility to the region's work force while also providing access to region's open space and myriad recreational opportunities.

The regional road and highway network is highly congested and many critical components of the network need repair. The congestion on Bay Area freeways, as measured by the daily vehicle hours of delay, has increased significantly from approximately 25,000 hours in 1981 to just over 160,000 (Caltrans District 4 HICOMP, 2008). Many of the major roads and highways, such as I-80 in Berkeley and U.S. 101 in the South Bay are situated between highly urbanized communities and/or critical infrastructure and the Bay, which constrains options for the expansion of the existing network. In other parts of the region, such as Highway 37 in the North Bay, the major roads and highways traverse the Bay and sensitive wetland communities. Avoiding adverse impacts on Bay resources creates additional challenges and constraints for road expansion and maintenance projects to address the current maintenance needs and relieve congestion.

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Figure 2.7

Area potentially exposed to an approximate 16-inch sea level rise
Area potentially exposed to an approximate 55-inch sea level rise
Port and Water-Related Industry
Airport
Waterfront Park, Beach
Major Roads and Highways
BART
Railroad

Grizzly Bay Transportation Network and Shoreline Priority Use Areas Potentially Exposed to Sea Level Rise

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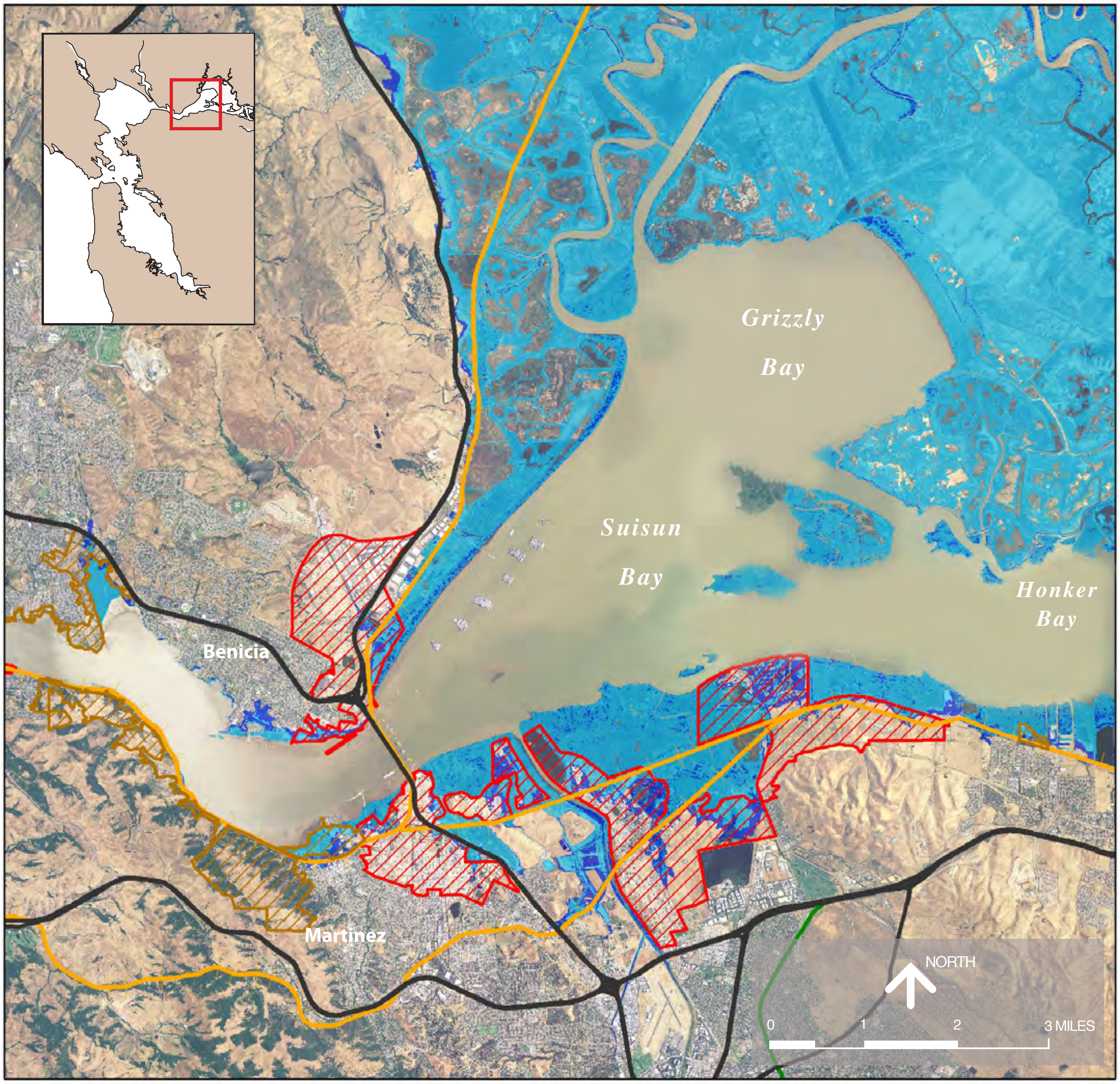


Sea level rise data provided by:
USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; BCDC, 2009; MTC, 2009.

Figure 2.8 Typical Section: Highway Adjacent to the Bay

Source: BCDC

Because of their proximity to the Bay, many of the major roads and highways within the region may be significantly impacted by sea level rise and extreme flooding events. Approximately 99 miles of the major roads and highways within the region are potentially exposed to a 16-inch rise in Bay water levels and approximately 186 miles of major roads and highways are potentially exposed to a 55-inch rise. Interstate 880 along the eastern shoreline of the South Bay, U.S. 101 in Santa Clara, San Mateo and Marin Counties, Highway 37 in the North Bay, I-680, and Highway 12 in Solano County include significant portions of roadway that are potentially exposed to flooding (Figure 2.5-2.7).

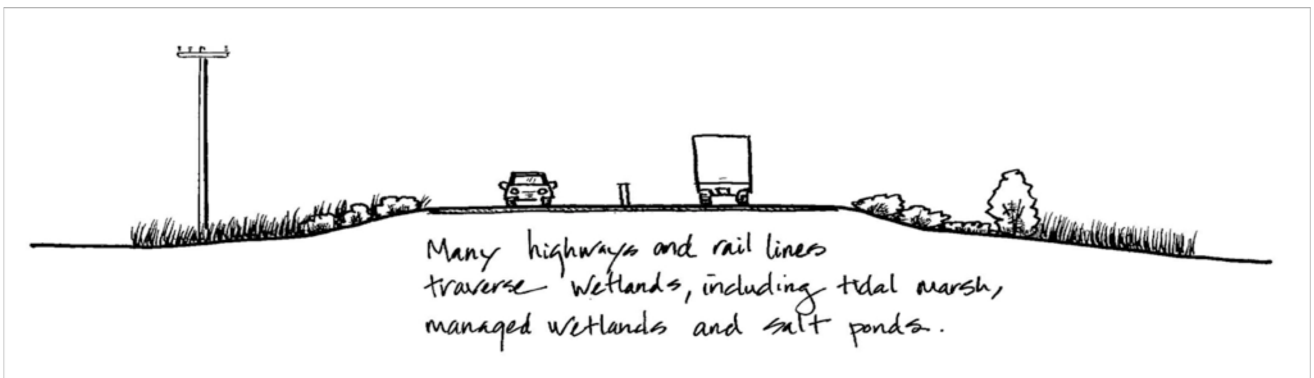
Many roads and highways will be subject to secondary impacts from sea level rise. For example, much of 1-80 along the Berkeley and Albany shoreline is not directly subject to flooding due to the existing elevation of the roadway (Figure 2.8). However, erosion from increased storm activity can undermine existing protective and/or highway structures, which can substantially increase the cost of maintaining the highway. Other secondary impacts may occur where traffic from one impacted road is diverted onto another road. Increased construction activity that is necessary to make transportation infrastructure more resilient to sea level rise can cause more congestion and impact residential communities adjacent to roadways. Congestion causes delays in the movement of goods throughout the region and adds time to residents' already lengthy commutes. Finally, the supporting structures of many of the region's bridges may be susceptible to unanticipated, prolonged contact with corrosive salt water.

Rail Network. The regional rail network has more than 600 miles of track, moves vast quantities of freight and passengers, and links the region with the Central Valley and inland areas (BCDC, 2005). Leading products moved by the rail system include, steel, waste, scrap, petroleum products, crushed stone and automobiles. (MTC, 2004). Freight service is provided by two Class I rail carriers, Union Pacific (UP), which links the region with Roseville and the

Central Valley, and Burlington Northern Santa Fe (BNSF), which links the region to Stockton and beyond. Many water-related industries, including oil refineries and auto terminals located along the shoreline of the East Bay rely heavily upon rail service. There are a number of locations along the rail network that link multiple transportation sectors. For example, intermodal areas are located near the Ports of Richmond and Oakland. These ports rely heavily on rail to transport inbound cargo containers to inland processing and manufacturing locations. Likewise, the rail network serves to bring cargo from inland locations for export to trading partners.

Passenger service links the major jobs centers in San Francisco, Oakland and San Jose with other Bay Area cities and towns and with inland cities in the Central Valley such as Sacramento and Stockton. The primary passenger rail service providers include, Bay Area Rapid Transit (BART), San Francisco MUNI, Caltrain, Amtrak's Capitol Corridor, and Altamont Commuter Express (ACE). BART is an especially critical component of the region's passenger rail network, providing commuter service for residents in Alameda, Contra Costa, San Francisco and San Mateo counties.

Figure 2.9 Typical Section: Highway or Rail Line Through Wetlands
Source: BCDC



Except for BART and MUNI, Bay Area railroads use the same tracks for both passenger and freight service, which creates significant congestion. At-grade rail crossings slow traffic on rail and surface roads. Furthermore, freight demand is expected to grow upwards of 350 percent over the next 50 years (MTC, 2007) and many of the rail lines are in highly urbanized areas where options for major modifications or expansion are limited. Other stretches of rail are bordered by sensitive Bay habitats and ecological communities, which further constrain options for rail expansion (Figure 2.9).

Approximately 70 miles of railroad are potentially exposed to flooding or permanent inundation with a sea level rise of 16-inches while 105 miles are potentially exposed to a 55-inch sea level rise. The rail segments that are particularly vulnerable to flooding include, the Central Corridor where it passes through the Suisun Marsh (Figures 2.7), the tracks along the northern Contra Costa shoreline near Martinez, the Caltrain corridor on the Peninsula, the ACE, and Capitol Corridor in the South Bay. Because these rail segments are shared by multiple users and already experience congestion, flooding could paralyze rail service regionwide. The economic impacts of a system-wide rail failure would be staggering. Furthermore, protection of this infrastructure from sea level rise will also be costly and may require funds to be redirected from projects that address current pressures on the system.

Waterfront Parks and Beaches

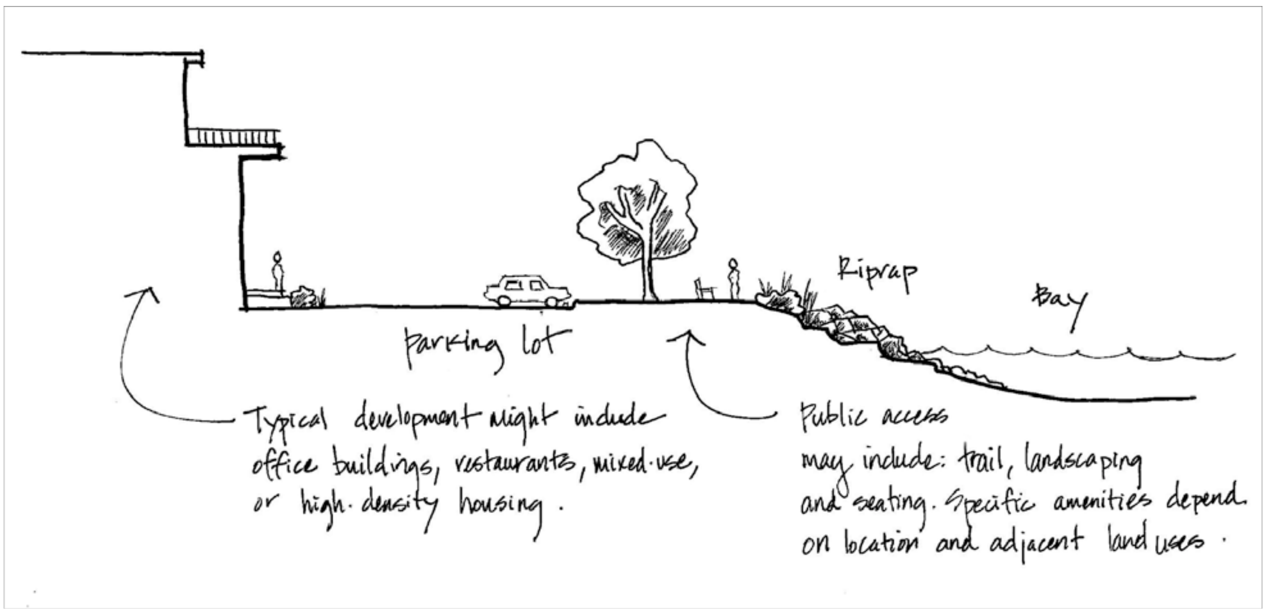
Waterfront parks and beaches promote enjoyment of the Bay, the region's most important open space, and enhance the quality of life for Bay Area residents. Recreation on the shoreline and in the Bay foster a life-long bond between residents and the Bay, improves their health, and provides a respite from the stress of living in a crowded, high-paced urban environment (BCDC, 2006). Recreational opportunities can be found at beaches, parks, marinas, shoreline trails and water trails, boat launches and fishing piers. People use waterfront parks, beaches, and public access to hike, bicycle, kayak, swim, fish or just watch the sunset.

The region has an average of approximately 95 acres (0.1 square miles) of open space per 1,000 residents, much of which is located in hills surrounding the Bay (BCDC, 2006). Available open space and recreational lands may not be able to keep pace with the region's growing population. In the 1990's, population grew at two percent while the addition to the open space only grew at 1.1 to 1.6 percent per year (Bay Area Open Space Council, 1999). Creating shoreline recreational opportunities that reflect the diversity in race, culture, age and income levels is another important challenge. Some communities, particularly on heavily urbanized parts of the shoreline, lack sufficient open space and recreational lands. Many of the waterfront parks and beaches are the most accessible recreation areas to the highly urbanized and diverse communities along the shoreline. Prospects for expanding shoreline and Bay recreational opportunities are further limited by their proximity to sensitive habitat, the cost of purchasing shoreline property, and the long-term maintenance and operations expenses. In many cases, remediation of contaminants may also increase the costs of converting some sites to waterfront parks.

Approximately 23,000 acres (35 square miles) are designated in the *San Francisco Bay Plan* as waterfront parks and beaches. Approximately 3,250 acres (5 square miles) or 14 percent of the region's waterfront park and beach areas are located in areas potentially exposed to flooding or permanent inundation with a 16-inch sea level rise. A 55- inch sea level rise would potentially impact approximately 4,300 acres (6 square miles) or 18 percent of the region's waterfront parks and beaches. As sea level rises, it will become more costly to maintain existing waterfront park and beach areas as well as to provide new recreational opportunities to meet the demands of a growing population. Furthermore, use of shoreline areas may increase as temperature increases result in more high-heat days. Finally, providing recreational opportunities along the shoreline that do not adversely impact sensitive ecological communities will likely contribute to the challenges of providing and maintaining shoreline recreational opportunities in the future, especially if sea level rise reduces the viability of Bay habitats.

Figure 2.10 Typical Section: Public Access

Source: BCDC



Public Access Required by BCDC

Another defining feature of the region's shoreline is the abundant and diverse public access opportunities that ring the Bay. Public access includes physical access to and along the shoreline as well as visual public access to the Bay from other public spaces. Shoreline public access includes waterfront parks, promenades, piers, trails, plazas, overlooks, and connections linking public streets to the Bay. BCDC has required shoreline public access as part of shoreline development since 1969. Every proposed shoreline development must provide "maximum feasible public access, consistent with a proposed project." As a result of BCDC permit requirements, there are 700 sites that provide over 300 miles of public access to and along the

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Figure 2.11

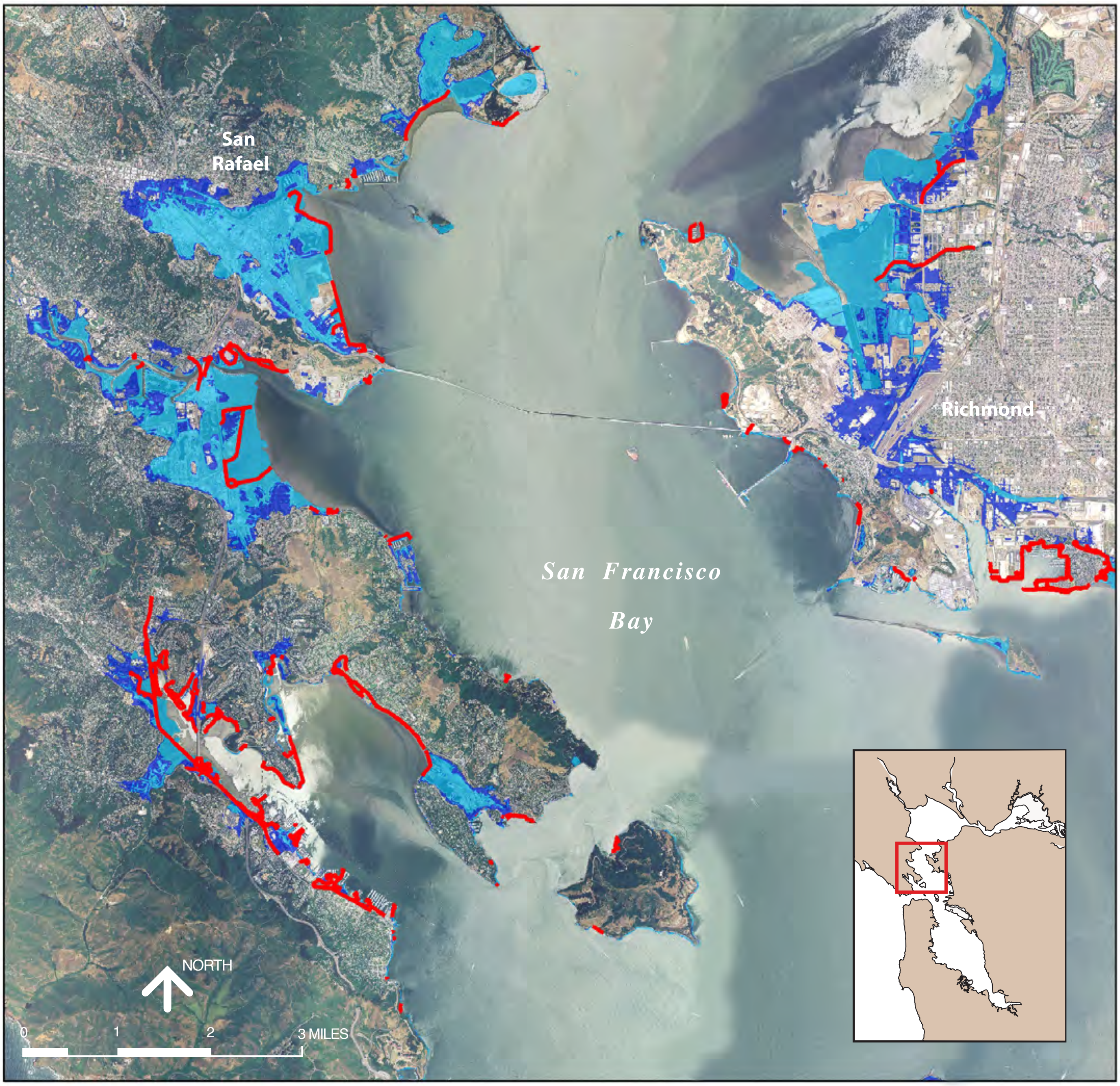
Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Public access required by BCDC

Central Bay North
Public Access Required by BCDC
Potentially Exposed To
Sea Level Rise

DISCLAIMER: *Inundation data does not account for existing shoreline protection or wave activity. These maps are for informational purposes only. Users agree to hold harmless and blameless the State of California and its representatives and its agents for any liability associated with the use of the maps. The maps and data shall not be used to assess actual coastal hazards,insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by the Federal Emergency Management Agency (FEMA).*



Sea level rise data provided by:

USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; BCDC, 2009.

San Francisco Bay Conservation and Development Commission

Figure 2.12

Area potentially exposed to an approximate 16-inch sea level rise

Area potentially exposed to an approximate 55-inch sea level rise

Public access required by BCDC

Central Bay West Shore Public Access Required by BCDC Potentially Exposed To Sea Level Rise

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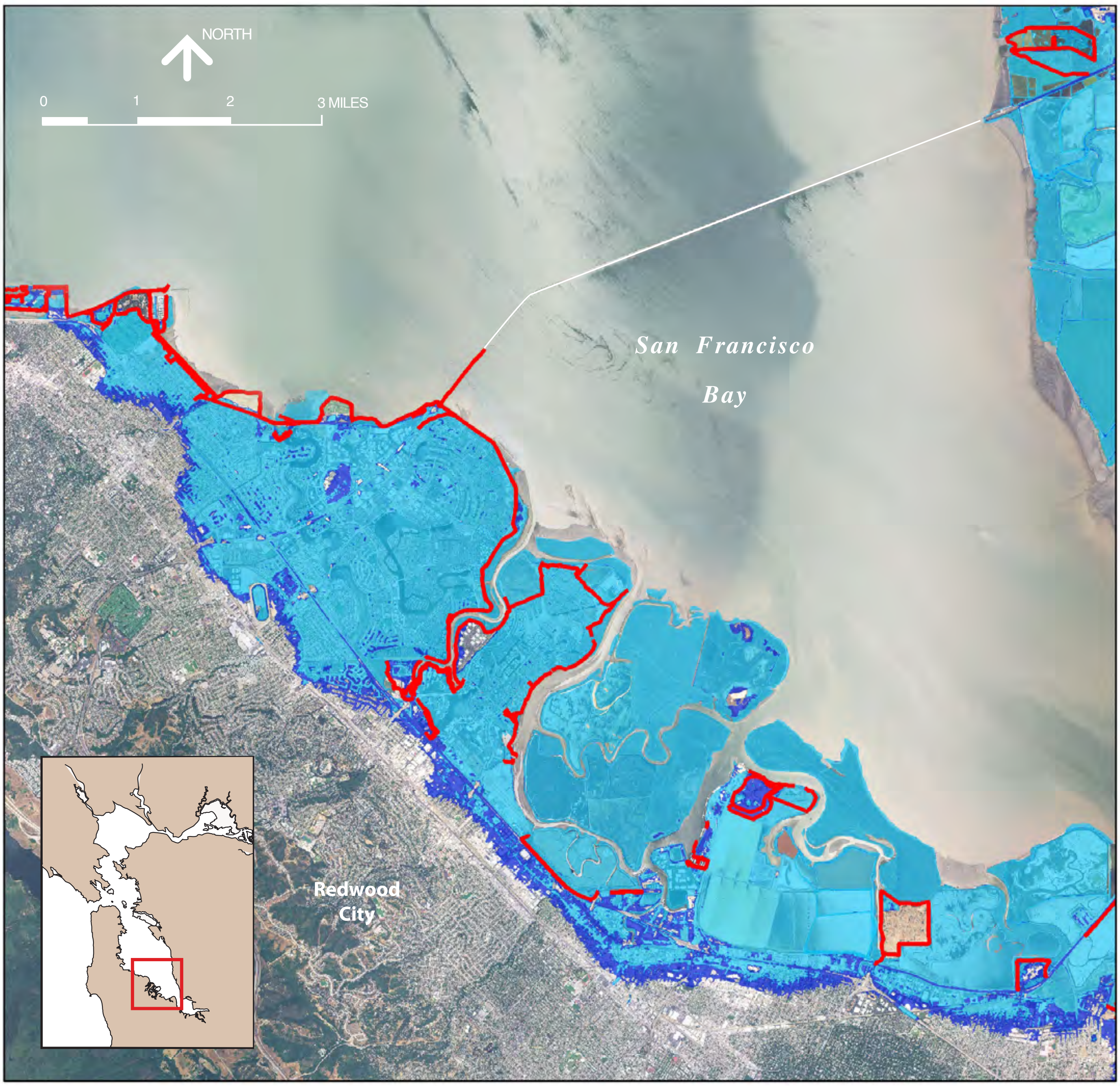


Sea level rise data provided by:

USGS
science for a changing world

SOURCE: Knowles, N. 2008. Siegel, S.W. and P. A. M. Bachand, 2002; BCDC, 2009.

approximately 1,000 miles of Bay shoreline. Public access generates regional benefits that are similar to waterfront parks and beaches. However, public access areas are usually smaller and associated with some type of development (Figure 2.10).

Many of the public access areas required by BCDC are also components of the San Francisco Bay Trail, which is a project to provide a recreational trail around the entire Bay. Some of the public access required by BCDC is part of a network of trailheads providing on-water access for non-motorized small boats and sail craft—the San Francisco Bay Area Water Trail.

The vast majority of public access is located within the Commission's 100-foot shoreline band jurisdiction (100 feet from the Bay) and, therefore, potentially exposed to flooding from sea level rise and storm activity. Over 400 public access sites, or approximately 57 percent, are located in areas that are potentially exposed to a 16-inch increase in sea level rise. Over 616 locations, approximately 87 percent, are located in areas exposed to a 55-inch increase in sea level rise (Figures 2.11 and 2.12). Public access located on elevated structures, such as fishing piers, bridges and wharves is not included in these estimates. The impacts to elevated public access features will largely depend on factors such as their design and construction as well as the resilience of the adjacent shoreline.

The increased likelihood of flooding will require difficult choices regarding the location, design and maintenance of existing and future public access. In urban areas, locating public access further inland may not be feasible. In open space areas, wildlife communities require adequate space and buffers to respond to sea level rise, which will further constrain public access siting and design options. Where structural shoreline protection is required, raising existing or constructing new structures may block physical and visual access to the Bay, especially where land has subsided. Access stairs or ramps to the top of shoreline protection structures may be necessary to provide access to the Bay. However, stairs or ramps may not satisfy the requirement to provide barrier-free public access to all, and new shoreline protection structures that also support public access will have to be designed with the needs of people with disabilities in mind. The widespread impacts to the region's existing public access will limit opportunities to provide a sense of visual continuity and connectedness for public access.

Summary and Conclusions

Residents, businesses and entire industries that currently thrive on the shoreline are subject to flooding by the middle of the century, and probably earlier. By mid-century, shoreline development located in the current 100-year flood plain will be subject to flooding from not just a 100-year flood, but from a high tide. A summary of these vulnerabilities is provided in Table 2.3. Approximately half of that development is residential, totaling 66,000 acres (103 square miles). Over 82,000 acres (128 square miles) of residential development is potentially exposed to flooding by the end of the century. Where residents are not directly vulnerable to flooding, access to important services such as commercial centers, health care, and schools would likely be impeded by flooding of the service centers or the transportation infrastructure that links

Table 2.3 Summary of Shoreline Vulnerabilities

Shoreline Uses	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	Adaptive Capacity	Vulnerability
Residential	Significant residential acreage and disproportion-ate amount of low-income residents.	Widespread flooding of approximately 270,000 residents and 82,000 residential acres (128 square miles).	High- Lost investments and/or relocating residents has major financial and social repercussions. Low-income residents are especially sensitive.	Medium- for those with the resources. Low- for low-income residents.	High
Airports	Subsided runways at SFO. Difficulty moving goods on land from SFO & OAK.	Flooding of 72-93% of acreage for airport operations. Secondary impacts to ground movement of cargo and passengers from flooding of transportation network.	High- Airports are critical to the regional economy. They are especially sensitive to primary and secondary impacts of flooding.	High- Shoreline protection for runways and upgrading important ground transportation is costly, but would likely be a high regional priority.	Medium-High
Ports	Difficulty moving goods via highways and rail.	Moderate flooding of ports (4-20% of total acreage). Most flooding impacts regional goods movement.	Medium-High- Ports are central to the regional economy. Rail lines and highways essential to goods movement are sensitive to flooding.	Medium- Goods movement is central to port activities. Ports are unlikely to be burdened with the cost of transportation infrastructure.	Medium-High
Water-related Industry	High business costs and job loss. Competing shoreline uses.	Localized flooding, that is especially troubling for individual sites (16-28 percent of total acreage)	Medium- The industry is already losing jobs, but flooding is localized rather than widespread.	Medium- Flood damage or new shoreline protection would be concentrated in a few areas.	Medium

Continuation of Table 2.3 Summary of Shoreline Vulnerabilities

Shoreline Uses Continued	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	Adaptive Capacity	Vulnerability
Major Roads and Highways	Congested and in need of repairs.	Widespread flooding (99-186 miles), including key highways and interchanges.	High- Many highways are adjacent to the Bay and cross the Bay. Flooding projected on some key passenger and truck routes.	Medium- Current congestion and maintenance issues make costly adaptations difficult.	High
Rail	Congested with multiple users sharing single tracks.	Widespread flooding (70-105 miles of track), including key segments.	High- Rail lines carry passengers and freight, are located on low-lying lands, and wetlands. Freight demand projected to grow	Low- Current location of tracks limits options for expansion or modifications..	High
Waterfront Parks and Beaches	Bay Area population is growing faster than recreational opportunities. Expensive shoreline property limits potential conversion to waterfront parks.	Moderate flooding relative to other shoreline uses (14-18 percent of waterfront parks). Beaches receive widespread flooding.	Medium- Waterfront parks provide a unique experience that requires a shoreline location, but will experience moderate flooding.	Low There are few available locations for waterfront parks.	Medium-High
Public Access	Public access is required on a project-by-project basis, making regional coordination challenging.	Widespread flooding of most public access (57-87 percent of public access sites).	High- Public access is not currently designed or sited to address flooding.	Low- Public access is unique to the shoreline. As the shoreline moves, public access must be designed to move with it, but upland movement may be blocked by development.	High

them. Rising sea levels can impact the delivery of petroleum products, electricity, and drinking water to Bay Area residents and businesses. The range of impacts can be more difficult for low-income residents because they generally have less financial flexibility and fewer resources to pursue alternative housing and transportation.

Water quality will suffer if wastewater treatment facilities, landfills or contaminated sites are flooded from sea level rise and storm activity. Compromised water quality and higher temperatures can result in algal blooms and a higher potential for the spread of water-born vectors.

Large commercial and industrial areas are vulnerable to flooding, especially in San Francisco, Silicon Valley, and Oakland. Approximately 72 percent of the San Francisco and Oakland airports is potentially exposed to a 16-inch sea level rise and 93 percent is potentially exposed to 55 inches of sea level rise, which can disrupt the transport of as much as 30 million passengers and approximately one million metric tons of cargo. Flooding of highway segments in the regional transportation network can disrupt the movement of goods from ports, which handled approximately 25 millions metric tons of cargo in 2007-2008. Other water-related industries would be similarly affected. Flooding of the rail system would be particularly serious, since multiple users share a single line in most locations around the Bay.

The Bay is a magnificent body of water that helps sustain the economy of the western United States, provides great opportunities for recreation, nourishes fish and wildlife, affords scenic enjoyment and in countless other ways helps to enrich our lives (Bay Plan, 2008). It is central to many activities in the region, whether traveling by car or rail along the shoreline, landing at an airport, strolling along the shoreline, or watching the fog stream in on a summer's day. Waterfront parks and public access provide opportunities to enjoy the Bay and remind us of its place in the region. There are 23,000 acres (35 square miles) of waterfront parks, of which 14 percent is vulnerable under the lower scenario and 18 percent is vulnerable under the higher scenario. Fifty-seven percent of the public access required by BCDC is vulnerable under the low scenario and 87 percent is vulnerable under the high scenario. The decline of waterfront recreational opportunities will impact the quality of life in the Bay Area and could affect the region's deep connection to the Bay.

To address the widespread flooding from storm activity and sea level rise, shoreline protection projects will be needed. Shoreline protection can be structural, natural, or a combination of both. Choosing the appropriate form of shoreline protection—one that both protects public safety and minimizes ecosystem impacts—is critically important. In the long-term, the region needs to engage in an open and vigorous public dialogue to make the difficult decisions about what to protect, and where and what kind of new development is appropriate in vulnerable areas, and areas where further development should be avoided.

CHAPTER 3
The San Francisco Bay Ecosystem

The San Francisco Bay, the largest estuary along the Pacific shore of North and South America, is constrained in its ability to adapt to climate change by the intensity of human uses in and around the Bay. The close proximity of urban and industrial development to the Bay dramatically reduces the adaptive capacity of the ecosystem and limits the potential for restoring additional habitats that could otherwise compensate for altered temperature, salinity, and sediment systems. The Bay provides many benefits to the surrounding human community while supporting numerous plants, animals, and migratory birds who feed on fish and shellfish (BCDC 2002). Maintaining these ecosystem benefits must be a key element of the region's climate change adaptation strategy.

Tidal wetlands provide critical flood protection and improve water quality by reducing and preventing shoreline erosion and filtering pollutants from surrounding areas. Tidal wetlands also store carbon in their soils (Mitch and Gosselink 2000, Trulio et al. 2007), which may help to mitigate climate change by sequestering GHGs. Tidal salt marshes in the South Bay sequester between 54-385 grams of carbon per square meter per year (Patrick and DeLaune 1990), an amount equivalent to at least 6,000 gallons of gasoline emissions (EPA 2005). Greco Island, one of the oldest tidal salt marshes in the Bay, sequesters 150-250 grams of carbon per square meter per year and has been doing so for at least 100 years (Callaway and Drexler, unpublished, cited in Trulio et al. 2007).

In many locations, humans have altered, degraded, or eliminated these ecosystem benefits. Roads, levees, dredging, and urban development have fragmented and destroyed much of the once contiguous shoreline habitats of the Bay. Sand mining, shell mining and dredging activities have altered subtidal habitats. There are now 40,000 acres (62 square miles) of tidal marsh, a reduction of 80 percent since the late 1800s. Similarly, tidal flats have been reduced up to 60 percent to 29,000 acres (45 square miles) from bay fill and erosion. Only seven out of an estimated 23 miles of former sandy beaches remain (Goals, 1999).

The existing Bay ecosystem is largely a managed environment. Elements of the Bay ecosystem continue to withstand pressures from climate change and human alteration, exhibiting remarkable resiliency. The adaptive capacity of the Bay ecosystem to withstand the rapid climate changes predicted for the next century depends both on the magnitude of impacts resulting from climate change and the management actions taken in response to those impacts. Further habitat loss resulting from climate change and future construction of levees and other flood protection infrastructure along the shoreline would threaten the survival of critically endangered species and natural communities. The challenge is to preserve the appropriate amount and diversity of habitats to maintain healthy species populations, while, at the same time, finding sustainable flood protection solutions for shoreline development and industry. Retaining the benefits that the Bay ecosystem provides will require a new management approach that recognizes the dynamic nature of the ecosystem. While past management strategies for the Bay ecosystem focused on conserving a static ecosystem or restoring a previous ecological state, new strategies must be based on anticipating future conditions, such as accelerating sea level rise, and implementing adaptive management as the ecosystem evolves over time.

Sea Level Rise in the Bay Ecosystem

Under current sea level conditions, the ebb and flow of the tides inundates the intertidal mudflats (tidal flats) and low to middle tidal marshes at the edge of the Bay on a regular basis, while storms and other extreme weather events cause occasional flooding of high marsh and upland areas. Low-lying areas behind levees also are flooded occasionally when levees are overtopped or fail due to storms, earthquakes or burrowing animals. The lower of the two sea level rise scenarios (16 inches) is sufficient to impact 90 to 95 percent of the existing tidal marshes and tidal flats by changing the frequency and duration of inundation. Of these tidal marsh areas, almost 20 percent exist lower in the tidal zone, which makes them vulnerable to permanent submersion and erosion (PWA and Faber 2004, Pacific Institute 2009). A 16-inch rise in sea level would also permanently flood approximately 70 to 75 percent of the subsided wetlands in Suisun Marsh if their fragile levees were to fail. The few remaining beaches (about 45 acres or 0.07 square miles) on the margin of the Central Bay are all vulnerable to sea level rise. Increased frequency and duration of inundation in some areas and permanent flooding of other areas induced by sea level rise would initiate a number of complex physical, ecological, and biological responses in estuarine ecosystems, which, when combined with other impacts of climate change, would increase the vulnerability of the Bay ecosystem. While wetlands can adapt to sea level rise, given sufficient sediment and room to migrate, armoring of the shoreline and other human impacts may hamper or prevent this and result in more loss of tidal marsh habitats.

Constraints to Wetland Adaptation. The shape of the Bay-Delta estuary formed over the past 3,000 years in response to gradual sea level rise and the circulation of sediment by tides, waves, and inflowing rivers (Byrne et al. 2001, Wells and Gorman 1994, Atwater 1979). The Bay-Delta estuary now supports a mosaic of habitats, extending from the subtidal water column where fish live to the tidal flats and tidal marshes. Tidal wetlands not only protect the shoreline from the flooding and erosive effects of storms, but also provide a setting for the surrounding communities to connect with the Bay ecosystem. Accelerated rates of sea level rise may outpace sedimentation in tidal flats and tidal marshes, which would lead to erosion and drowning of these habitats in the Bay-Delta estuary.

Tidal flats in the Bay are already eroding as a result of insufficient volumes of sediment from tributary watersheds. The area of tidal flats in the North Bay decreased by 68,000 acres (106 square miles) over the period from 1951-1983, and 4,500 acres (7 square miles) in the South Bay between 1858 and 2005 (Jaffe et al. 2007, Jaffe and Foxgrover 2006). The decline in sediment flowing into the Bay is the result of dam construction, flood control, water diversions and other management actions in the tributary watersheds.

Early studies estimate as much as 80 to 90 percent of the sediment reaching the Bay came from the Sacramento and San Joaquin rivers (Krone, 1979; Porterfield, 1980). During the Gold Rush era, hydraulic mining in the Sacramento and San Joaquin watersheds resulted in approximately 590 million cubic yards of sediment being deposited in the Bay and a 60 percent increase in the area of tidal flats over the period from 1856 to 1887 (Jaffe et al. 2007). Much of this mining sediment contains mercury, which was used to extract gold and is now widespread in Bay sediment. Under some conditions, such as increased acidity, the inorganic mercury in this sediment can be converted to methylmercury, a highly toxic form.

In 1884, the California Supreme Court (Sawyer Decision) outlawed the discharge of mine tailings to rivers. This decision dramatically reduced the volume of sediment that was coming from the Sacramento and San Joaquin watersheds by the early 1900s (Porterfield, 1980), despite the ongoing logging, urbanization, and agricultural development, activities that typically cause soil erosion. A primary cause for the continued sediment decline during the 20th century was the construction of dams for water supply that prevented sediment from reaching the Bay (Krone, 1979; Ogden Beeman and Associates and Krone and Associates 1992).

From the 1940s to the 1970s, the damming of rivers trapped sediment in both the Sacramento and San Joaquin watersheds and local tributaries of the Bay (e.g., Napa River, Sonoma River, and Alameda Creek). Damming also reduced flood flows, limiting the capacity of rivers to transport sediment from the Delta to the Bay (Porterfield, 1980; McKee et al. 2006;

Wright and Schoellhammer, 2004). Now, research demonstrates that sediment from local tributaries to the Bay may constitute as much as 43 percent of the annual sediment delivered to the North Bay (McKee et al. 2006), and the loss of tidal flats is an indication that the Bay watersheds are contributing less sediment.

Subsidence of diked areas further complicates the restoration of tidal wetlands, which would aid the Bay's ability to adapt to sea level rise. Sites planned for tidal marsh restoration are, in many cases, subsided two to six feet below mean sea level (e.g., South San Francisco Bay, Suisun Marsh) (PWA and Faber 2004, Watson 2004, Poland & Ireland 1969, Orr et al. 2003), which is substantially lower than the elevation at which marsh plants usually grow. A fundamental component of tidal marsh restoration is the recruitment of native plants, which thrive under specific flooding conditions that are controlled by their elevation with respect to the tides. The target elevation can be achieved by placing dredged material on site or by promoting natural sediment deposition through re-suspension and transport of muddy sediment from tidal flats. Once an adequate elevation is reached, marsh plants tend to colonize the site and initiate organic matter accumulation, which aids the tidal marsh in keeping up with sea level rise (PWA and Faber 2004, Orr et al. 2003). Regional partnerships such as the Long-Term Management Strategy (LTMS) for dredged material from the San Francisco Bay Area (LTMS Plan 2001) are already working to address the decline in sediment supply by maximizing the beneficial use of dredged material for wetland restoration.

However, higher rates of sea level rise may jeopardize efforts to restore tidal wetlands and maintain the current form of the Bay-Delta estuary. Erosion of subtidal areas may also expose mercury-laden sediment and impact circulation patterns in the Central Bay, possibly contributing to scour of bottom sediment, a primary physical control on habitats in subtidal regions of the Bay (NOAA 2007). The erosion of tidal flats and tidal marshes would result in additional loss of recreational, flood protection, and water quality benefits.

In order for estuarine migration to occur, gently sloping areas of transitional habitat containing a combination of wetland and upland features are needed. These wetland-upland transition zones are high in species diversity and also provide refuge for endangered species like the salt marsh harvest mouse and the California clapper rail during high tides. These areas could potentially evolve into tidal marsh habitat as sea level rises. However, wetland-upland transition zones have been almost entirely eliminated due to development of the Bay shoreline in close proximity to the upland edge of tidal habitats. In many areas, the wetland-upland transition zone consists of only a few feet of vegetation along the steeply sloping side of a levee.

Salinity Change in Tidal and Subtidal Habitats. Higher salinity due to climate change will stress plant communities and species of concern in the Bay, and some may not thrive or persist in the face of this impact (Callaway et al. 2007, Spalding and Hester, 2007). Climate change has the potential to impact estuarine salinity in three main ways: (1) changes in total precipitation; (2) changes in seasonal patterns of precipitation and runoff, i.e., a shift from snow to rain and earlier snowmelt; and (3) sea level rise.

These salinity shifts may be moderated or exacerbated by management of reservoirs and water diversions (Callaway et al. 2007). Water managers rely on freshwater conditions in the Delta to preserve drinking water supplies for the growing populations of the Bay Area and Southern California, as well as the agricultural lands and brackish habitats of Suisun Marsh. These goals are accomplished by releasing water from reservoirs during spring, summer, and autumn when there is less rainfall and higher temperatures.

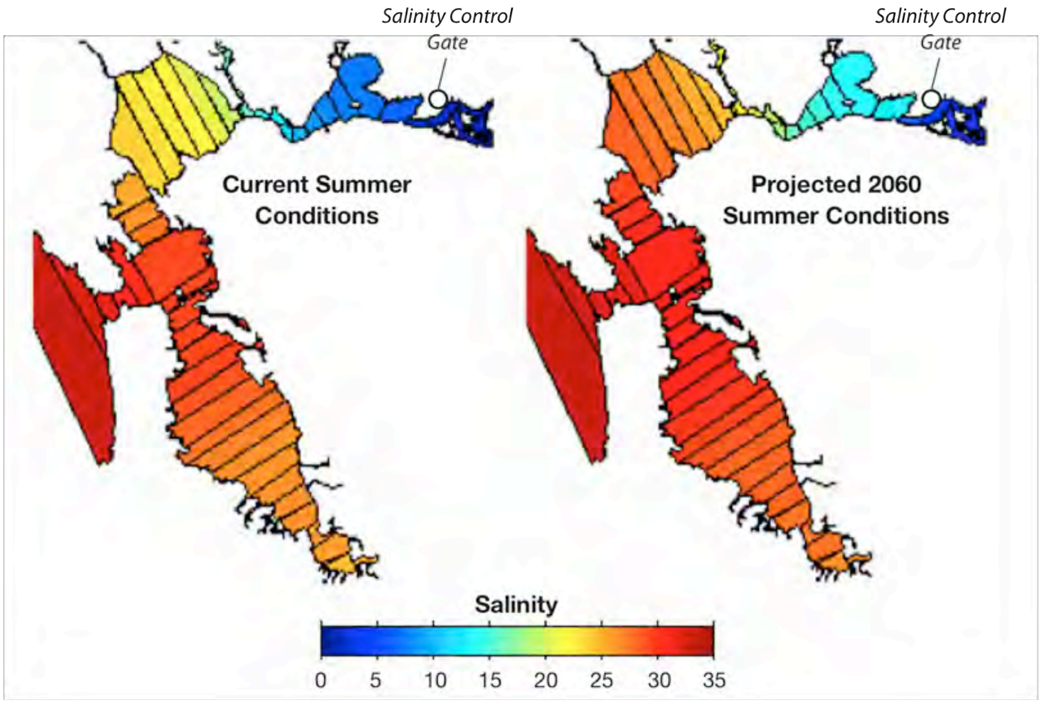
California's water reservoirs are designed with the assumption that a large portion of the state's water will be stored in the snowpack. Warmer temperatures associated with climate change are projected to result in more precipitation falling as rain instead of snow in the winter, causing a 50 percent loss of the Sierra snowpack by 2090. Warmer temperatures will also melt the snowpack earlier in the year (Figure 3.1) (Knowles and Cayan 2002). Earlier snowmelt would require water managers to release excess water from reservoirs, causing more water to flow into the Suisun Marsh and the Bay following winter storms and reducing flows at other times of the year (Barnett et al. 2008). For example, spring flows (April-June) are expected to decline from 36 percent of total annual flow in 2030 to 20 percent of total annual flow in 2090 (Knowles and Cayan 2002).

The shift in freshwater flows from spring to winter is projected to increase salinity in the South Bay, San Pablo Bay, and especially Suisun Marsh (Knowles and Cayan 2002). Infrequent flushing from the tides in high marsh areas, especially during summer months, make these areas particularly vulnerable to salinity shifts (Callaway et al. 2007). High marsh areas are particularly important because they contain many of the rare and endangered species that are found in California tidal marshes (Baye et al. 2000).

Salinity increases due to climate change may dramatically impact the brackish and freshwater marshes found in Suisun Marsh and near the confluence with Bay tributaries. Since brackish and freshwater tidal marshes tend to be more productive and provide habitat for a greater diversity of plants than salt marshes, elimination of these valuable wetlands or their conversion to salt marshes could reduce the habitat available to rare and endangered species (Callaway et al. 2007, Newcombe and Mason 1972, Baye et al. 2000, Lyons et al. 2005).

Figure 3.1 Salinity Change in San Francisco Bay

SOURCE: Dr. Noah Knowles, USGS



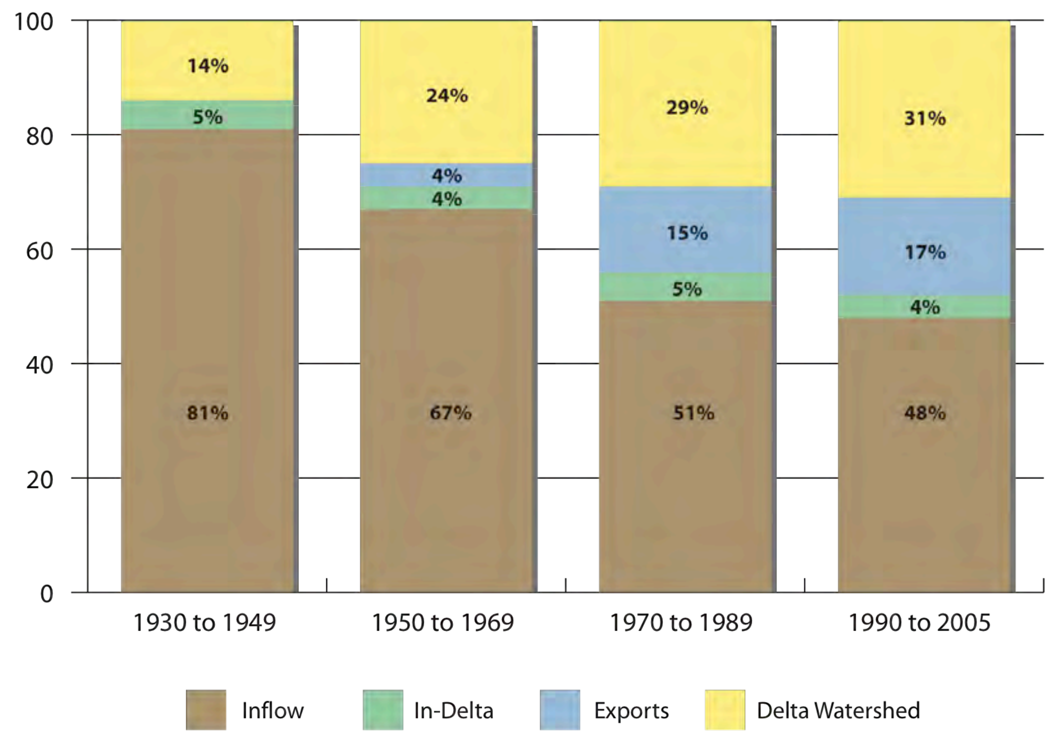
Wet-Year summer salinity field shifts upstream 10-15km due to reduced spring/summer snowmelt runoff

Efforts to use water control structures, such as salinity gates, to artificially reduce salinity in Suisun Marsh in dry years are likely to become increasingly difficult in the face of climate change. The Suisun Marsh Salinity Control Gates (Figure 3.2) restrict the flow of higher salinity water from incoming tides and retain low-saline, Sacramento River water from the previous outgoing tide. An eastward shift of the salinity gradient caused by sea level rise will likely reduce opportunities for importing freshwater into the Suisun Marsh.

These impacts from climate change heighten an already complex debate over water management. Exports from the Sacramento-San Joaquin Delta (Delta) by the state and federal water projects, water use in the Delta watershed, and in-Delta water use have reduced the total volume of water entering the Bay. Flows from the Delta account for about 90 percent of freshwater flows to the Bay, while ten percent of flows come from the watersheds surrounding the Bay (San Francisco Estuary Project, Aquatic Habitat Institute 1991). A comparison of annual averages from the years 1930-1949 and the years 1990-2005 shows that outflow from the Delta to the Bay has been reduced from 81 percent to 48 percent of total flows (Figure 3.2) (Delta Vision 2008).

Figure 3.2 Changes to Freshwater Inflow to the Estuary

SOURCE: Delta Vision 2008



To address the impacts of water diversions, the United States Environmental Protection Agency (EPA) and United States Fish and Wildlife Service (FWS) established a water quality standard for salinity, referred to as X2, to ensure adequate minimum freshwater inflow to the Bay to benefit the reproductive success and survival of the early life stages of many estuarine species[1] (Kimmerer 2002). The X2 measurement corresponds to the upstream location of the mixing zone of fresh and salt water and moves eastward or westward, both seasonally and from year-to-year, depending on the volume and timing of freshwater inflow. The standards require X2 to be maintained at particular locations within the Delta and Suisun Bay between February and June, depending on the amount of precipitation.

The anticipated impacts from climate change and the increasing demand for drinking water and agriculture will limit the ability of water managers to maintain the X2 standard. Inability to maintain X2 may contribute to the extinction of fish species, some of which are a vital economic resource. Fish, such as the threatened Delta smelt and endangered salmon, rely on higher flows in winter and spring, which may be difficult to maintain with less water available in reservoirs (Kimmerer 2002).

Other Water Quality Impacts

Increases in air temperature, salinity, and changes in precipitation and runoff patterns will impact both the Pacific Ocean and the tributaries flowing into the Bay, threatening water quality and human health. Warmer air temperatures may prevent cool waters in the Pacific Ocean, rich in oxygen and nutrients, from circulating to the surface and to various parts of the California coast, including the Bay (Roemmich & McGowan 1995, Harley et al. 2006). When combined with numerous new and existing pollutants and altered tidal circulation, these effects may produce algal blooms resulting in reduced water oxygen levels.

The increased carbon dioxide concentrations in the atmosphere that are causing global warming are also causing the world's oceans to become more acidic. This is because carbon dioxide dissolves into ocean water and increases acidity. Levels of acidity in the ocean may exceed any found in the 200-300 million year fossil record (Caldeira & Wickett 2003, Feely et al. 2004, Harley et al. 2006). This impact may endanger most of the world's coral reefs.

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[1] X2 is defined as the distance upstream from the Golden Gate Bridge to the point where daily average salinity at one meter from the bottom is two parts per thousand (Jassby et al. 1995).

High carbon dioxide levels will increase the acidity of Bay waters as well. Although the effects on the Bay are unknown, high levels of acidity may prevent organisms from forming shells and skeletons of calcium carbonate because of a chemical reaction that dissolves calcium carbonate into its constituent ions when acidity is high (Doney et al., 2009). In the Bay, it could particularly impact organisms at the base of the food web that form carbonate shells, such as bivalves, crustaceans and copepods.

Invasive and Migrant Species

The geographic ranges occupied by certain species will shift in response to changing environmental conditions due to climate change. While the impacts of climate change may harm or benefit a particular species, the shifting of conditions under which native species evolved will aid invasive species (i.e., non-native species that spread quickly and crowd out native species) or native species that are either better adapted to the changed conditions or more tolerant of a wide range of conditions. For example, warmer conditions will make the Bay more hospitable to migrant species from the south, and species adapted to a wide range of temperatures will fare better those that require colder conditions to survive.

Invasive species and expanding populations of some natives can threaten other native species through competition for resources, predation, parasitism, interbreeding with native populations, transmitting diseases, or causing physical or chemical changes to the invaded habitat (California Natural Resources Agency 2009). Climate change may increase the potential for invasive species to become established and spread in the Bay, resulting in a loss of native biodiversity and native species that are vital to our economy (e.g., salmon).

The spread of invasive species would further impact one of the most highly invaded estuaries in the world (Cohen and Carlton 1998). In many cases, invasive species are introduced through boat hulls, ballast water, and intentional introductions for commercial and recreational use. The Asian clam (*Corbula amurensis*) was introduced into the northern Bay in the 1980s and, through an explosive increase in population, replaced the resident clams and began filtering enough algae from the water column to significantly reduce the food available to other species (Carlton et al. 1990).

Two non-native crab species, the green crab and Chinese mitten crab, contribute to erosion and loss of marsh habitat through burrowing in tidal channels. In addition, smooth cordgrass (*Spartina alterniflora*) can outcompete native cordgrass, altering vegetative structure and habitat for endangered species, such as the California clapper rail. The spread of smooth cordgrass to tidal flats may inhibit the exchange of sediment from tidal flats to tidal marshes, preventing marsh migration and impacting migratory bird populations.

In addition, species that are native to certain parts of the state may migrate to new regions and some resident natives could experience increased population growth that could potentially alter community structure and species interactions (California Natural Resources Agency 2009). Recent population bursts among native corvids (crows and ravens) and California gulls are examples of native species population increases that intensify competition for resources and predation on native species.

In the long run, maintaining native biodiversity will require accommodating the movement and migration of multiple native species (California Natural Resources Agency 2009) as well as migrating species. For example, preserving the species native to brackish marshes may require creation of habitat corridors that connect these habitats to freshwater marshes, which will become brackish over time as salinity moves further inland due to sea level rise.

Threat of Extinction

The Bay ecosystem supports a diverse range of threatened and endangered species. Climate change impacts, such as warmer water temperatures and reductions in the amount of tidal marsh, are likely to make it harder to recover threatened and endangered species and may cause more species to become threatened and endangered.

The plummeting populations of several species of Delta and North Bay fishes during the early 2000s is referred to as the pelagic (open water) organism decline (POD). The abundance indices for 2002-2004 include record lows for the Delta smelt and young striped bass and near-record lows for threatened longfin smelt and threadfin shad. The POD has been attributed to a combination of factors: toxins, such as pesticides and herbicides; invasive species, such as the such as the overbite clam, which consumes plankton and other food needed by small fish; and the huge pumps used for state and federal water project operations, which entrain small fish and impact salinity and circulation patterns in the estuary.

The Delta smelt is listed as threatened by the U.S. Fish and Wildlife Service and as endangered by the California Department of Fish and Game. Warmer estuarine waters resulting from climate change will further increase the risk of extinction for this and other fish species dependent upon cold water. Water temperatures beyond 25 degrees Celsius are lethal to Delta smelt, a threshold that is already reached in the estuary during summer heat waves.

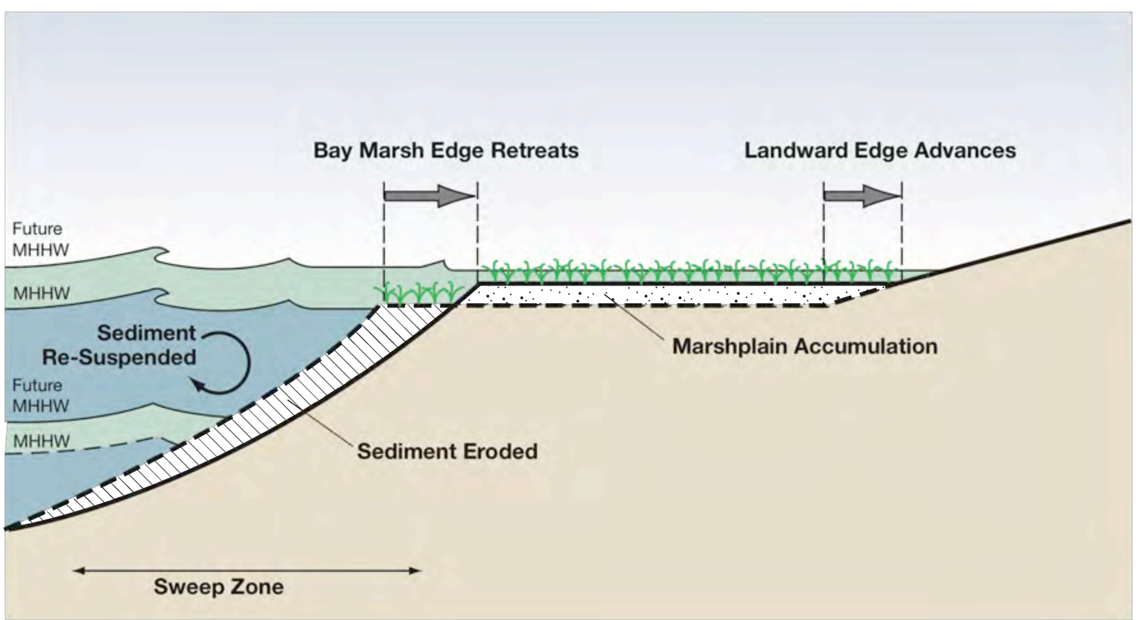
The endangered California clapper rail and salt marsh harvest mouse seek refuge in high tidal marshes and upland transition zones during extreme high water events. Sea level rise and declining sediment supply threaten high marsh and upland transition zones that act as refugia for the clapper rail and mouse, posing a significant challenge to providing adequate habitat to enable the recovery of these species.

Tidal marshes and tidal flats are important habitat for a number of bird species migrating along the Pacific Flyway. For many birds who rely on tidal marshes and flats, the loss of breeding habitat results in smaller populations. As tidal habitats are lost or degraded, some birds may move to other less suitable habitats, but reproduction in degraded habitats tends to be lower and mortality tends to be higher. The birds that breed in these poorer quality habitats may eventually become threatened or endangered (Pulliam and Danielson, 1991).

Although resource managers are shifting their emphasis from single-species management to an ecosystem-based management approach, preventing extinction remains an important goal and is required by the state and federal endangered species acts. In addition, monitoring the abundance of threatened and endangered species, particularly those that provide early warning of climate change, is critical to ensuring the health of the Bay ecosystem.

Figure 3.3 Estuary Migration

SOURCE: Lowe and Williams, 2008



Shoreline Protection Impacts

Static structures have been constructed on tidal marshes and tidal flats, a practice that restricts migration of the Bay ecosystem landward during sea-level rise. Shorelines move upward and landward with sea level rise, forming tidal marshes and tidal flats further inland. As sea level rises, high-energy waves erode mud from tidal flats and deposit that sediment onto adjacent tidal marshes (Figure 3.3). Plants establish on tidal marshes trapping additional sediment and accumulating organic material. If sedimentation and organic accumulation in tidal marshes is sufficient, tidal wetlands persist on the Bay shoreline in the same relative position, rising at the same rate as sea level (PWA and Faber 2004, Watson 2004). If sedimentation is slower than sea level rise, tidal marshes and tidal flats begin to erode and the area in front of shoreline protection structures converts to open water (PWA and Faber, 2004, Lowe and Williams 2008).

Because tidal marshes and tidal flats decrease wave heights or attenuate waves, the loss of tidal marsh seaward of protection structures further exacerbates potential flooding and erosion during storms by allowing larger waves to reach the structures. Studies in the United Kingdom (Möller 2001, 2002, 2006) estimate that salt marshes in front of levees reduce wave heights by as much as 40 percent, reducing required levee height and lowering the total cost of the levee by 30 percent (Turner and Dagley 1993). Seawalls, in particular, create a hard, smooth surface that reflects wave energy back onto the shoreline, eroding and undermining the base of the structure and leading to failure (BCDC 1988a). Riprap revetments dissipate this energy somewhat, but are also vulnerable to erosion at the base of the structure and at each end (BCDC 1988a). Sea level rise requires that engineers retrofit existing structures to protect against larger waves, usually by raising the height of the structure and by strengthening the seaward base (Lowe and Williams 2008, Smits et al. 2006, Heberger et al. 2008).

Ecological Consequences of a Tidal Barrage. In 2007, BCDC reported on the potential impacts on San Francisco Bay from a tidal "barrage" across the Golden Gate (barrage is the technical term for a barrier or dam across a waterway). It is foreseeable that such a structure could be proposed as an alternative to the extensive shoreline protection structures that may be built in response to sea level rise. After the North Sea flood in 1953, the Dutch sacrificed entire estuaries to build similar structures. The results of BCDC's study indicate that constructing a barrage at the mouth of San Francisco Bay would likely be physically and economically impractical, as well as ecologically damaging. The ecological consequences of the barrage would likely be very high. It would affect sedimentation, wetlands, fresh and salt water mixing, animal migration, and endangered species. More than likely it would change the landscape of the Bay Area, affecting the North Bay and South Bay most heavily.

Damming the Bay would result in less salt water entering the Bay and more fresh water being trapped within. Overall the Bay would become more brackish and less saline. Exchange of nutrients and plankton between the ocean and Bay would also be greatly reduced. There would be reduced ability to assimilate wastewater discharges, resulting in reduced water quality and the need for expensive modifications to wastewater treatment facilities.

A barrage would likely greatly decrease sediment exchange between the Bay and the ocean. The reduced sediment load has the potential to increase coastal erosion. Currently scientists and planners are examining whether the existing wetlands will be able to keep pace with sea level rise. As sea level rises in the ocean, a barrage would decrease tidal range in the Bay, eliminating many intertidal areas by converting them to subtidal areas, further decreasing Bay tidal flats and wetlands.

Fish and marine mammals are likely to be the most affected as migratory pathways would be greatly reduced, and species using the Bay as a nursery ground, such as Dungeness crab and many species of flat fish, would be blocked. Changing the salinity regime would also eliminate species that require higher salinities from the Bay. Birds that are dependent on marine fish for food and shorebirds that depend on the mud flats would likely have to relocate. Science has shown that the Bay is one of the most important stops of the Pacific flyway, altering this habitat would have global effects on birds that stop here on their yearly migration.

The Bay is home to numerous threatened and endangered species such as Chinook salmon, steelhead and green sturgeon. Sturgeon have been known to go through lock systems but only on an accidental basis. Placing fish gates and ladders in the barrage would alleviate some of the issues, but creating obstacles for already stressed and endangered species only pushes them further towards extinction. Reducing fish populations would also affect endangered least terns and brown pelicans, reducing their chances for survival.

While creating a barrier to sea level rise may seem to solve flooding issues due to storm surges and rising ocean waters, it may exacerbate flooding inside the Bay during heavy winter storms. Reducing the ability of fresh water to be released into the ocean would cause severe flooding if excess water has no place to go. Should long-term sea level rise exceed 6.56 feet (2 meters), then tidal flows would no longer be possible and outflow from tributaries would require pumping through the barrage.

Watershed Land Use

Watershed management must account for the need for sediment to feed Bay marshes and mudflats, while not hampering pollution control or increasing sediment impacts to creeks that require clean gravels for spawning salmon and steelhead trout.

Inflowing waters and sediments from local tributary watersheds of the San Francisco Bay are increasingly recognized as important components of a healthy Bay ecosystem (Collins and Grossinger 2004). Tributaries of the Bay contribute freshwater and sediment that help sustain the tidal marshes and tidal flats where rivers meet the Bay (Collins and Grossinger 2004, Grossinger et al. 2007). Approximately ten percent of the tidal flats in the Bay and Delta are in the tidally influenced portions of major tributaries of the Bay.

However, natural flows of water and sediment from watersheds to the Bay have been altered by development. Urbanization in Bay area watersheds has led to increases in paved, impermeable surfaces, construction of storm drains, and culverting and channelization of creeks. As a result, during storms, rain that is unable to soak into the ground flows over paved surfaces, washing accumulated pollutants into storm drains, creeks and, eventually, the Bay. Faster, more concentrated storm flows enter creeks, increasing channel erosion and bank undercutting, which degrades fish habitat and undermines bridges, buildings and trails located along creeks. In some areas, flooding has become more severe.

Over ten years of research for the Regional Monitoring Project (RMP) has shown that sediment is the main transport mechanism for pollutants entering the Bay (Schoellhammer 2007, Flagel and Davis 2007). Total Maximum Daily Loads (TMDLs) limiting suspended sediment in creeks under the federal Clean Water Act have established a regulatory mechanism for reducing pollutant loads into the Bay and protecting salmon and steelhead spawning habitat. Localities have begun implementing best management practices such as floodplain setbacks and easements, infiltration basins, and creek and riparian habitat restoration, in order to accommodate flood flows and limit sediment and pollutant loads to creeks and the Bay.

However, given the decrease in sediment supply and loss of tidal flats, fine sediment supply from watersheds could be critical for maintaining equilibrium in tidal marshes, particularly in light of sea level rise. The challenge for future watershed management strategies will be to enable sufficient amounts of clean sediment to pass through watersheds to the Bay, while avoiding adverse impacts to fish and water quality (Box 3.1).

Restoration and Adaptive Management

Managing the health of the Bay requires a regional process to establish goals for the protection and restoration of wetlands or Baylands, ensuring the cumulative success of individual efforts. The Baylands Ecosystem Habitat Goals report (Goals), released in 1999, represents a consensus among area scientists and resource managers. It serves as a guide for sustaining diverse and healthy communities of fish and wildlife resources in the San Francisco Bay Estuary by providing recommendations for the necessary kinds, amounts, and distribution of baylands and related habitats. The Goals provide a flexible vision for restoration that translates into tangible actions.

In the decade since its release, over 75 projects have been initiated to restore baylands along the fringes of San Pablo Bay, South Bay, Suisun Marsh, and throughout the Sacramento-San Joaquin Delta. These projects range in size from just a few acres to some 15,000 acres (23 square miles) of salt ponds in the South Bay. Roughly 67,000 acres (104 square miles) have been restored to natural areas or are planned for restoration (Wetland Tracker 2008). These projects represent a tremendous public investment in preserving the baylands for future generations; however, the impacts of climate change may jeopardize that investment if the Goals are not updated to account for climate change.

Box 3.1 Shoreline Management and Watershed Management Planning

Shoreline Management. Shoreline management plans generally address erosion and flooding hazards in coastal areas. They are widely used in the United Kingdom and the European Union to plan for the effects of sea level rise. Shoreline management planning involves dividing the shoreline into a series of natural units or drift cells within the shoreline planning area and developing a management plan for each cell. The shoreline management plans further divide the cells by land use and develop strategies for the following 50-100 years, such as: holding the line, managed realignment (similar to managed retreat), or no intervention. In the UK, the Department of Environment Flood and Rural Affairs developed guidelines with which strategies must be consistent. Implementing the strategies is left to the local authorities. Shoreline management plans are designed to be regularly updated to effectively adapt to changing circumstance and new scientific information as the climate conditions change (DEFRA 2007).

The advantages of shoreline management plans are similar to watershed management plans where they avoid a piecemeal approach by setting clear guidelines for a specific planning area that is determined based on ecosystem processes, such as littoral drift cells or a watershed. This is especially effective for managing shoreline erosion because the each individual hard shoreline structure that is approved can cause erosion on adjacent properties and eliminate potential marsh migration areas.

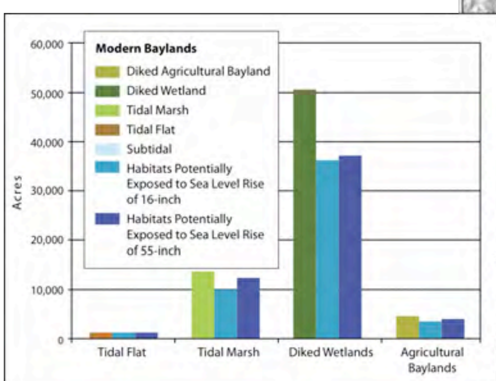
Watershed Management. Integrated watershed management is a planning concept developed to reconcile competing uses that degrade watersheds. It aims to meet multiple objectives across large spatial scales by coordinating the actions of numerous communities and sectors (MEAM 2008). Some primary goals of integrated watershed management are to provide adequate freshwater flow for ecosystem and human needs, maintain healthy riparian habitat and water quality, and mitigate past and future watershed impacts.

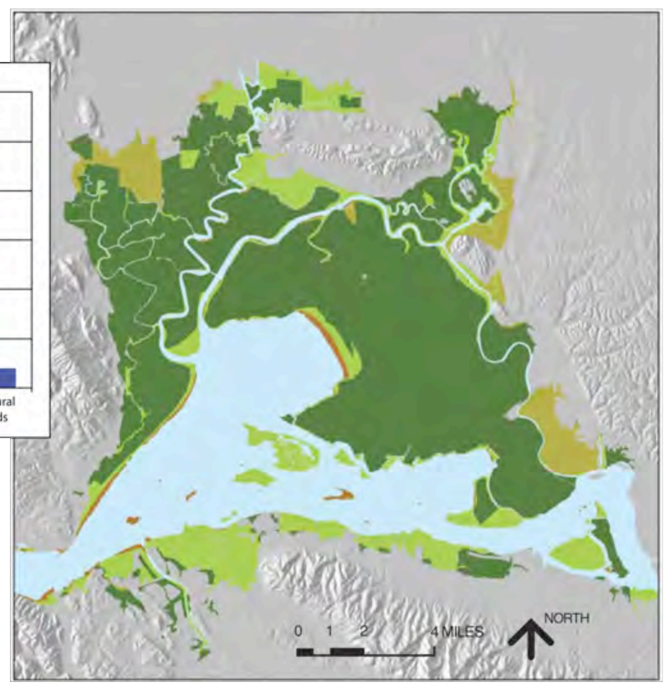
There are many examples of watershed (or catchment) management frameworks and programs around the world. Locally-based programs, such as the California Coastal Commission's Critical Coastal Area program (http://www.coastal.ca.gov/nps/cca-nps.html), aim to track and minimize contaminants and development pressures throughout an entire watershed, e.g., Sonoma Creek, upstream of San Francisco Bay. Other examples, such as the Bay Area Integrated Water Management Plan (IRWMP), aim to develop regional cooperation between many resource agencies and local stakeholders, in many cases resulting in a watershed management plan. Watershed management plans reflect a set of common goals that meet the needs of the watershed community, including humans and ecosystems.

Climate change impacts may require updating the Goals as regional targets for types, amounts, and distribution of habitats to ensure that we maintain and expand the invaluable resources that the Baylands provide. Within the next 10 to 50 years, the Baylands will face more flooding of potentially greater magnitude that could erode or degrade water quality and existing wildlife habitat in irreparable ways. While restoring historic habitat conditions may not be feasible, restoring ecosystem function is essential for enable habitats to adapt to the new stressors and challenges resulting from climate change. The best available science must be used to strategically select restoration sites that are likely to continue to provide ecological services as they evolve in response to sea level rise and other climate change impacts.

Figure 3.4 Suisun Marsh Habitats Potentially Exposed to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)





IMPACTS ASSOCIATED WITH SEA LEVEL RISE

- **Levee failure and higher salinity in freshwater wetlands**
- **Warmer water temperatures**
- **Loss of species (e.g. Delta Smelt)**
- **Lack of sediment for marsh accumulation**
- **Erosion of tidal wetlands and subtidal areas**
- **Spread of invasive species**

Suisun Marsh (Figure 3.4). The Suisun Marsh Charter Group formed in 2001 to develop a new restoration and management plan for the Marsh. The first phase of the Suisun Marsh Plan will involve converting between 2,000 and 9,000 acres (3 and 14 square miles) of managed wetlands to tidal marsh and enhancing between 39,000 and 46,000 acres (60 and 72 square miles) of managed wetlands to benefit a variety of species.

Tidal restoration objectives include restoring tidal marshes contiguous with upland transitions; expanding the distribution and amount of sloughs and shallow subtidal habitat; restoring natural processes, increasing productivity and nutrient export to adjacent Bay waters; and enhancing populations of listed and sensitive native species (Wilcox 2006). Constraints to tidal restoration include subsidence, limited sediment supply, protecting infrastructure, effects on salinity, protection of neighboring properties and reduction of managed marsh. Since most of the managed wetlands in the Marsh are at or below sea level and sediment supply is limited, breaching levees would create shallow water habitat rather than tidal wetlands in many areas (Figure 3.4).

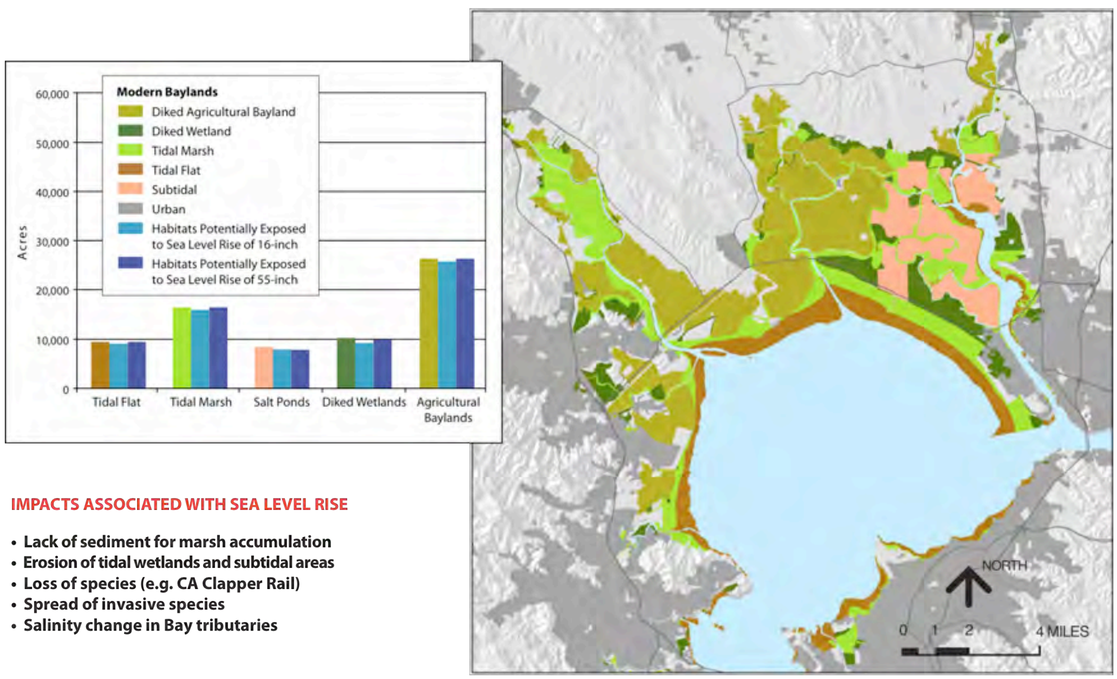
Tidal restoration opportunities will be constrained by their salinity effects on other parts of the Delta, particularly those areas where water is withdrawn for export by the state and federal water projects. Levee failure in diked wetlands would increase salinity variability by returning them to tidal action if the levees were not repaired. If a major earthquake or flood were to cause catastrophic levee failure and the flooding of several Delta islands, the tidal prism would increase dramatically, resulting in increased salinity in the Bay and Suisun Marsh, as well as changes in erosional and depositional patterns in the estuary (Healey 2008). The Suisun Marsh Plan will have to consider the potential salinity impacts of sea level rise, climate-induced changes in the hydrological regime of the Bay-Delta Watershed, and proposed changes in storage and conveyance by the state and federal water projects.

Sea level rise will make managed wetlands increasingly difficult to maintain. Higher water levels will put more pressure on fragile levees, increasing the risk of failure. Sea level rise will also reduce managers' ability to use gravity to periodically drain the wetlands in order to flush out salts and manage vegetation by discing and planting.

North Bay (Figure 3.5). Most of the North Bay supports a mix of diked agricultural baylands, managed wetlands, and tidal marsh. The Petaluma and Napa Rivers and Sonoma and Tolay Creeks also flow into the North Bay, supporting large areas of brackish marsh. Currently, approximately 14,000 acres (22 square miles) of Baylands are restored or are in the process of being restored to tidal habitat in the North Bay. An additional 10,000 acres (15 square miles) are planned for tidal habitat restoration, despite recent erosion of the tidal flats in the North Bay. Tidal flats in the North Bay are replenished increasingly by sediment from local tributaries such as the Napa River and Sonoma Creek. These local tributary watersheds are sufficiently large to supply adequate amounts of sediment. However, current watershed management practices, such as damming, are reducing sediment throughput to the Bay, leading to erosion of the tidal flats and marshes.

Figure 3.5 North Bay Marsh Habitats Potentially Exposed to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)

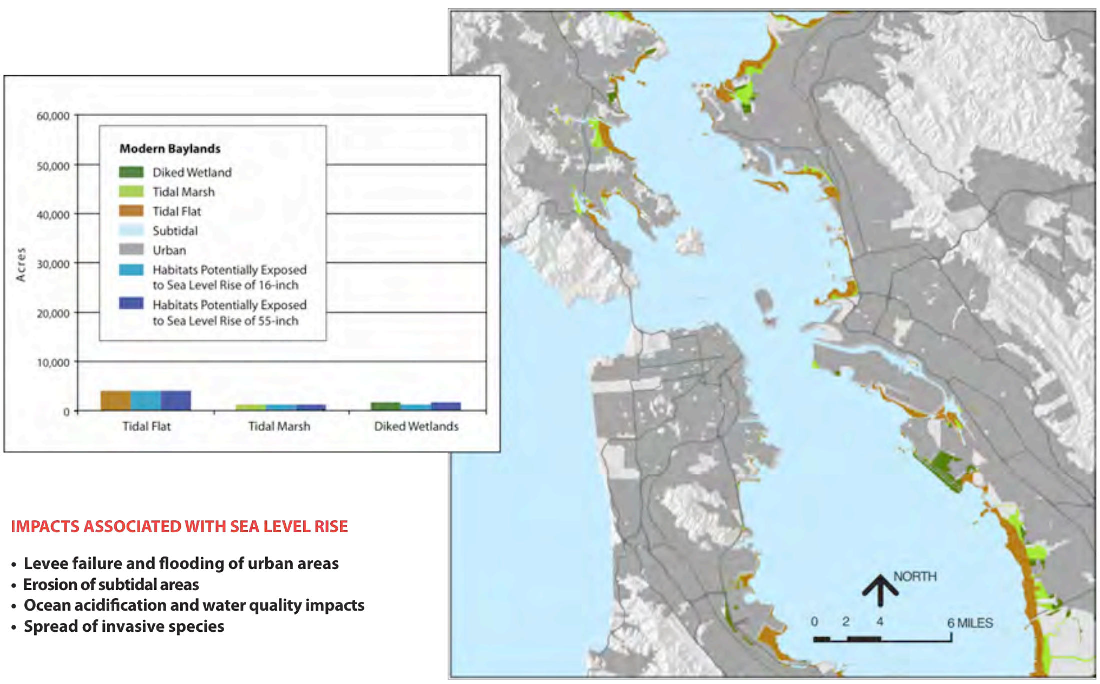


Central Bay (Figure 3.6). Subtidal areas are the dominant habitat in the Central Bay, which includes the Golden Gate, San Francisco and Oakland shorelines. It is the deepest part of the Bay, and thus, is the central shipping corridor. Most of the shoreline is developed with riprap revetments or bulkheads. However, the largest eelgrass beds in the Bay are located here. Eelgrass beds provide shelter and food to small fish, and Pacific herring lay their eggs on eelgrass (State Coastal Conservancy 2010).

The Subtidal Habitat Goals Project, led by BCDC, the California Coastal Conservancy, the California Ocean Protection Council, the National Oceanic and Atmospheric Administration (NOAA), and the San Francisco Estuary Partnership, is a collaborative effort to advance the understanding of submerged habitats, such as eelgrass beds, in San Francisco Bay. The project provides the basic information needed for planning conservation, restoration, research, and management activities related to subtidal habitat in the San Francisco estuary. The project report contains an appendix on climate and other long-term changes likely to affect the future of subtidal habitats (State Coastal Conservancy 2010).

Figure 3.6 Central Bay Habitats Potentially Exposed to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)



South Bay (Figure 3.7). The South Bay is the focus of the largest tidal restoration project ever planned for the Pacific Coast, the South Bay Salt Ponds (SBSP) restoration project. Preliminary design for the SBSP project involves restoration of 15,000 acres (23 square miles) to a mixture of tidal flat, tidal marsh, and transitional habitat. The project's goals are to restore and enhance wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation. The project seeks a balance between restoring wetland habitat and maintaining existing pond habitat, with alternative scenarios ranging from 50 percent each of wetlands and ponds to 90 percent wetlands and ten percent ponds. The project participants identified eight key uncertainties that could make meeting the project objectives difficult. These included sediment dynamics, bird response to changing habitats, non-avian species responses, mercury issues, invasive and non-native species, water quality, public access and wildlife, and social dynamics. The overarching uncertainty of global climate change is incorporated into each of the specific key uncertainties.

Figure 3.7 South Bay Marsh Habitats Potentially Exposed to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)

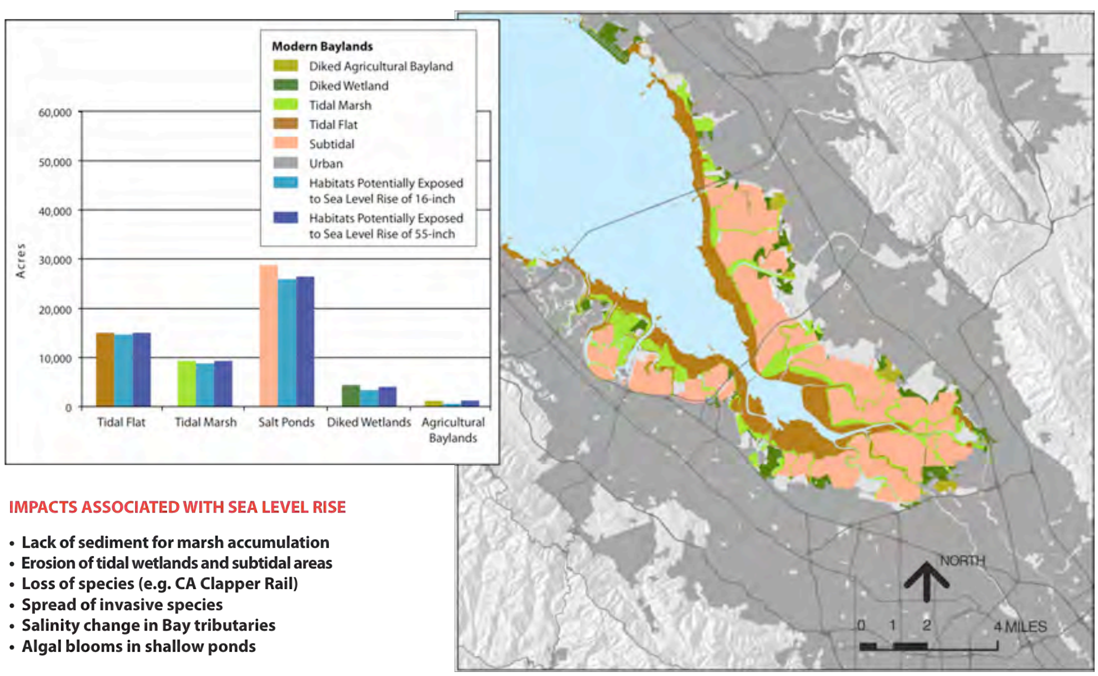


Table 3.1 Summary of Vulnerabilities in the Bay Ecosystem

Bay Ecosystem Subregions	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	**Adaptive Capacity**	**Vulnerability**
Suisun Marsh	Subsided wetlands that rely on salinity gates to restrict the flow of higher salinity water into the Marsh. Older levees constructed on peat.	Potential flooding from levee failure. Change in salinity. Loss of species. Lack of sediment. Erosion and invasive species.	High – Subsidence and older levees make the Marsh very sensitive to flooding. Salinity changes can significantly alter habitats.	Low/Medium – Without levee improvements and rethinking management strategies, the Marsh will suffer. Marsh has space to migrate upland.	High
North Bay	Tidal flats are eroding, reducing sediment supply to marshes. Brackish marsh has high biodiversity, but requires freshwater inflow.	Increased erosion and lack of sediment for restoration. Invasive species and loss of biodiversity. Salinity changes near and in tributaries.	High – Managed wetlands are especially susceptible to erosion. Brackish marsh is relatively unique habitat in the Bay.	Medium – Current rates of erosion and lack of sediment may hamper marsh restoration efforts and upland migration. Plentiful open space is available for upland migration.	Medium High
Central Bay	Intense human activity, including shipping, dredging, mining and industrial uses that threaten eel grass beds and impact water quality.	Erosion of subtidal areas. Acidification and other water quality impacts. Spread of invasive species. Major structural shoreline protection to protect urban shoreline can increase erosion.	Medium – Unique subtidal habitats, like eel grass beds, are difficult to restore and their limited numbers could result in total loss.	Medium Low - Eel grass beds may not be adaptable. A great deal of uncertainty remains regarding the effects of acidification and salinity. Little space for marsh migration.	Medium
South Bay	Major restoration efforts will require sufficient amounts of sediment for success. Levees surrounding salt ponds are older and may require improvements.	Lack of sediment for marsh accumulation and increased erosion. Spread of invasive species. Algal blooms in shallow ponds.	High - Current restoration efforts require adequate sediment to succeed.	Low - Although restoration will improve ecosystem functions, little space is available for marsh migration.	High

Initial investigation of the impacts of sea level rise on the SBSP project suggest that sufficient sediment exists to raise subsided sites to elevations suitable for plant growth. However, long term replenishment of the tidal flats, a critical source of sediment, may be in jeopardy if resource managers do not successfully manage sediment in the South Bay. Potential adaptive management actions to address sediment supply include: incorporating monitored changes in sediment supply and mudflat distribution into project phasing; using low-crested levees along the bayfront edge to reduce wave energy, protect restored tidal areas, and encourage marsh sedimentation; reconnecting existing mudflats to salt ponds to allow for natural sedimentation; using dredged material to raise pond elevations to a level conducive for growth of vegetation, augmenting natural sedimentation; and prioritizing restoration in ponds adjacent to intertidal mudflats and/or ponds at higher elevations which will require less dredged material and natural sediment supply to offset migration from sea level rise.

Summary and Conclusions

The Bay is inhabited by numerous plants and animals and provides many benefits to humans. For example, tidal wetlands provide critical flood protection, improve water quality, and sequester carbon. Brackish marshes in the North Bay and Suisun Marsh support the greatest diversity of species and provide an important resting place along the Pacific Flyway. The impacts of climate change will substantially alter the Bay ecosystem by inundating or eroding wetlands and transitional habitats, altering species composition, changing freshwater inflow, and impairing water quality. Changes in salinity from reduced freshwater inflow will affect fish, wildlife and other aquatic organisms in intertidal and subtidal habitats. The highly developed Bay shoreline constrains the ability of tidal marshes to migrate landward, while the declining sediment supply in the Bay reduces the ability of tidal marshes to grow upward as sea level rises. The vulnerabilities from future climate change are further summarized in Table 3.1.

The Bay will continue to evolve in response to the climatic forces that enabled it to come into being. Historic modification of the ecosystem, through filling, diking, and building on the shoreline and reducing freshwater inflow, as well as ongoing stressors such as pollution and invasive species, have resulted in the decline of many native species and increased the vulnerability of surrounding communities to damaging floods. Substantial progress has been made in restoring the Bay ecosystem by returning diked areas to tidal action and reducing pollution, while efforts to increase freshwater inflow have been less successful. Future efforts to restore the Bay ecosystem can benefit from careful design that accounts for the known processes affecting formation of habitats in the Bay, the constraints imposed by existing stressors, and the future vulnerabilities.

Key issues that resource managers must address regarding climate change include: identifying opportunities for tidal wetlands and tidal flats to migrate landward, managing and maintaining adequate volumes of sediment for marsh sedimentation, developing and planning for natural flood protection, and maintaining sufficient upland buffer areas around tidal wetlands. Furthermore, habitats, like beaches, should be high priority for restoration and conservation.

Developing effective strategies to protect tidal wetland and tidal flat from sea level rise is challenging because the projections of future sea level rise continually change. This range of variation, based on different climate models and emission scenarios, creates a great deal of uncertainty for decision-makers; therefore, wetland protection strategies must be adaptable to changing conditions.

CHAPTER 4
Governance: What BCDC and Local Jurisdictions Can Do

The vulnerabilities of the Bay shoreline and ecosystems to sea level rise and other climate change impacts will create new technical challenges for shoreline planning, and require difficult decisions to prioritize protection of shoreline development and Bay resources. This chapter assesses the vulnerabilities in Bay Area governance systems that may hinder the region's ability to meet these challenges. The analysis begins by identifying vulnerabilities in the overall organization of government agencies and their authorities, and then focuses on BCDC and local governments because of their central roles in adapting to the impacts of climate change on the Bay and its shoreline.

BCDC is addressing regional adaptation for a variety of reasons. The Commission has authority over San Francisco Bay and shoreline from just outside of the Golden Gate Bridge to the Delta, and its laws and policies establish the agency's responsibility for protecting and enhancing the Bay, and encouraging the Bay's responsible use. As one of California's federally-designated state coastal management agencies, BCDC has access to state and federal resources to support coastal management, and the authority to review federal and federally-permitted activities under the federal Coastal Zone Management Act (CZMA). The Commission also has an integral regional role in planning for the Bay through its participation in the Joint Policy Committee, and its partnerships with other federal, state, regional and local agencies and organizations.

This chapter also lays out the needs of local jurisdictions to effectively address the challenges climate change will pose to their communities. Understanding these needs is essential because local governments have broad land use authority and thus a clear responsibility to adapt to climate change.

The Governance Landscape

BCDC's regional authority and local governments' land use authority give these agencies primary roles in adapting to sea level rise impacts, but they are just some of the many government agencies that are relevant to adaptation planning in the Bay Area. Management authority over Bay and shoreline resources is sliced up among numerous other government agencies as well. Provision of services such as flood control and water supply and quality is managed by different local, regional, state, and federal agencies based on authorities granted to them through various federal, state, and local laws and policies. These sectoral management activities intersect geographic boundaries of agency jurisdiction and land ownership that define the Bay region's parks, wildlife areas, residential communities and industrial and commercial areas. Together, these divisions create a patchwork of jurisdictions and authorities that challenges the region's ability to respond to broad geographic and cross-sectoral impacts such as those expected with a changing climate. In the Bay Area, a number of multi-jurisdictional planning programs have successfully addressed complex environmental issues but, too often, have failed to follow through. Examples of successful follow-through include the Long Term Management Strategy's Dredged Materials Management Office and permit streamlining, the South Bay Salt Pond Restoration Project, and hazard mitigation planning.

These challenges are not all unique to adaptation planning. Other regional and sub-regional planning efforts such as the South Bay Salt Ponds Restoration Project, an effort led by the State Coastal Conservancy, and the Multi-Jurisdictional Local Hazard Mitigation Plan, led by the Association of Bay Area Governments (ABAG) (Box 4.1), have faced similar cross-jurisdictional and sectoral issues. These efforts have relied on inter-agency partnerships and extensive outreach to key stakeholders and the public to effectively integrate and address the diversity of authorities and interests relevant to these projects.

However, despite many similarities to past planning efforts, adaptation planning involves additional complexities that government agencies have not previously had to address. Whereas past regional planning efforts have been able to assume a (basically) static environment, or "backdrop" for the planning project, the entire impetus for and context of adaptation planning is a changing environment. Added to this changing backdrop are complexities that are uncommon to other planning projects: climate change impacts are slow to develop and long lasting, but create environmental changes that are relatively rapid compared to historic change; expected intensities of impacts are well beyond the range of historic effects; uncertainty about expected impacts is very high; and there is a dearth of experience in rapidly assessing the efficacy of adaptation actions. These complexities magnify the importance of conducting comprehensive regional planning for adaptation, yet exacerbate the challenges associated with this type of planning. These challenges present yet another situation where too many authorities can make it difficult to be flexible in planning for and responding to these complex and relatively rapid changes. Some balance of redundancy and flexibility is required.

Box 4.1 Hazard Mitigation Planning in the Bay Area

Effective adaptation planning is limited by the number of and divisions among management authorities in the Bay Area. These existing governance challenges will be exacerbated by climate change impacts. Agencies have had to address overlapping jurisdictions and authorities in other Bay Area regional planning efforts. Preparation of the Multi-Jurisdictional Local Hazard Mitigation Plan (Plan) for the Bay Area is one example of this.

Development of the Plan was a "joint effort by the cities, counties, and special districts in the Bay Area to build a more disaster-resistant region," and to meet requirements of the federal Disaster Mitigation Act (DMA) of 2000 for all local governments to develop and adopt this type of plan. The Association of Bay Area Governments (ABAG) coordinated this multi-jurisdictional planning effort to identify hazards to communities, assess risks, and develop a disaster resistance goal and objectives, and a comprehensive list of strategies (or actions) to mitigate the identified risks. ABAG conducted numerous workshops with local governments to determine the scope of work, identify key hazards and develop mitigation strategies for eight different planning, or "commitment," areas. Once the overall Plan for the Bay Area was completed, each city, county and special district prepared an "annex" to the Plan with a more specific assessment of hazards and risks within its jurisdiction, and prioritization and application of mitigation strategies. (For the 2005 Plan, more than 90 local governments prepared annexes.)

In the Plan, ABAG highlights two important characteristics of hazard mitigation that are also true of adaptation planning. First, it recognizes that "disasters do not respect the boundaries between … individual jurisdictions," and that hazard mitigation requires coordinated, cross-jurisdictional planning. Second, it recognizes that hazard mitigation planning is iterative and that the Plan needs periodic updates.

This example of a regionally-coordinated, multi-jurisdictional planning effort offers possible lessons for adaptation planning. The DMA has clear financial incentives for local governments to participate in hazard mitigation planning in the form of disaster recovery grants that become available to municipalities that have plans in place. Assessing vulnerabilities to hazards such as floods, fire and earthquakes requires extensive geographic data analysis. Instead of each local government conducting a separate data collection and mapping effort, ABAG compiled available data and created interactive, web-based mapping tools that allowed each jurisdiction to assess its vulnerabilities within the different commitment areas. This ensured consistency of the analysis across the many jurisdictions, and minimized the workload for local governments.

This planning effort is an opportunity for improving the region's adaptive capacity to climate change impacts. As the Plan is updated, the hazard mitigation strategies can be expanded (as appropriate) to address relevant climate change impacts such as sea level rise. Taking advantage of opportunities to integrate adaptation planning into this existing effort could reduce the amount of additional work that climate change will create for local and regional planners.

In the Bay Area, five federal agencies are actively involved in shoreline adaptation: the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the United States Army Corps of Engineers (Corps), and the Environmental Protection Agency (EPA). As one example of federal involvement, the Corps is partnering with the State Coastal Conservancy and the Santa Clara Valley Water District to conduct the South San Francisco Bay Shoreline Study, which will identify project alternatives and recommend for federal funding for one or more projects for flood damage reduction, ecosystem restoration and related purposes such as public access. Although flooding risks from creeks have been reduced by a number of existing projects in the area, the area remains vulnerable to tidal flooding, and is expected to become more vulnerable as sea level rises. This project is being closely coordinated with the South Bay Salt Ponds Restoration Project, which is discussed in Chapters 3 and 5.

The state has numerous agencies that are actively addressing climate change adaptation. To date, BCDC has worked primarily with three of the agencies that have been instrumental in funding and managing important research projects related to sea level rise in San Francisco Bay: the California Energy Commission's Public Interest in Energy Research program, the

California Coastal Conservancy, and, more recently, the Ocean Protection Council. BCDC also works with the regional agencies on the Joint Policy Committee to carry out the JPC's climate change strategies. Several nearby regional agencies are taking an active role in planning for climate change in the Delta and the Suisun Marsh: the Delta Protection Commission, the Delta Stewardship Council, the Delta Conservancy, and the Suisun Marsh Charter Group. The Commission provides a staff member to coordinate with these regional efforts.

The Commission's Jurisdiction and Authority

The Commission was established in 1965 as the nation's first state coastal management agency. Alarmed by the fact that between 1850 and 1960 an average of four square miles of the Bay was filled each year, citizens in the Bay Area successfully organized to advocate for new state legislation that would protect the Bay. The McAteer-Petris Act was passed in 1965 to establish BCDC as a temporary state agency. The Commission was charged with preparing a plan for the long-term use of the Bay and regulating development in and around the Bay while the plan was being prepared.

The *San Francisco Bay Plan* (Bay Plan), which was completed in January 1969, includes policies to protect the Bay as a resource and policies to guide development of the shoreline, ranging from ports and public access to water quality and habitat. The Bay Plan also contains maps of the entire Bay that designate shoreline areas that should be reserved for water-related purposes like ports, industry, waterfront parks, airports, and wildlife refuges. The Commission is directed to pursue an active planning program to study Bay issues so that Commission plans and policies are based upon the best available current information.

In August 1969, the McAteer-Petris Act was amended to make BCDC a permanent agency and to incorporate the policies of the Bay Plan into state law. In 1977, the Suisun Marsh Presrvation Act expanded the Commission's authority to provide special protection of the Suisun Marsh. The Suisun Marsh Protection Plan includes policies that guide the Commission and local jurisdictions in their review of marsh development permits as well as the Commission's review of local protection plans developed by local jurisdictions within the marsh.

BCDC is the federally-designated state coastal management agency for the San Francisco Bay segment of the California coastal zone. This designation empowers the Commission to use the authority of the federal Coastal Zone Management Act to ensure that federal and federally-permitted or funded activities are consistent with the McAteer-Petris Act and the Suisun Marsh Preservation Act and Protection Plan, BCDC regulations, and the policies of the Bay Plan.

Because the Commission was created in response to rampant filling of the Bay and a dearth of shoreline public access, the primary focus of the Commission's authority is on preventing unnecessary fill in the Bay and improving public access. Although fill is defined very broadly, this focus limits the ability of the Commission to address climate change issues.

The Commission's Jurisdiction. The Commission has jurisdiction over San Francisco Bay, including the Suisun Marsh, certain named waterways, salt ponds, managed wetlands, and a 100-foot shoreline band. Section 66610 of the McAteer-Petris Act describes the area of the Commission's jurisdiction over San Francisco Bay as follows:

> …"all areas that are subject to tidal action from the south end of the Bay to the [mouth of the] Golden Gate (Point Bonita-Point Lobos) and to the Sacramento River line (a line between Stake Point and Simmons Point, extended northeasterly to the mouth of Marshall Cut), including all sloughs and specifically, the marshlands lying between mean high tide and five feet above mean sea level….

The Commission typically refers to the above description as its Bay jurisdiction. Section 66610 also describes the Commission's shoreline band jurisdiction, which includes the land "between the shoreline of San Francisco Bay…[as described above] …and a line 100 feet landward of and parallel with that line." The Commission does not have shoreline band jurisdiction upland and adjacent to certain named waterways, salt ponds or managed wetlands.

In the 1970s, the Commission worked with other agencies and advocacy groups to develop the Suisun Marsh Protection Plan, which was enacted into law with the passage of the Suisun Marsh Preservation Act of 1977. The Act gives the Commission permit authority over an approximately 89,000-acre primary management area. Local jurisdictions retain permit authority over a 22,500-acre secondary management area, pursuant to their local protection programs approved by the Commission.

The Commission's Permit Authority. Section 66632 of the McAteer-Petris Act grants the Commission authority to require permits for projects in "any water, land or structure, within the area of the Commission's jurisdiction" for the following activities: (1) the placement of fill; (2) the extraction of materials; and (3) any substantial change in use of any water, land or structure. It further requires that projects provide "maximum feasible public access."

1. **Fill.** The McAteer-Petris Act broadly defines the term "fill" to include "earth or any other substance or material, including pilings or structures placed on pilings, and structures floating at some or all times and moored for extended periods…." Projects that involve the placement of fill in the Commission's Bay and certain waterway jurisdiction must be

consistent with Section 66605 of the McAteer-Petris Act, which requires the Commission to perform a tiered analysis. First, the Commission must determine whether the public benefits of the fill exceed the public detriment. Then, the Commission can approve fill only for a water-oriented use or minor fill to improve shoreline appearance or public access. Finally, the fill can be approved only when: (a) there is no alternative upland location for the fill; (b) it is the minimum amount of fill necessary to achieve the purpose of the fill; (c) the nature, location and extent of the fill minimizes harmful effects to the "environment," as defined in the California Environmental Quality Act (CEQA); (d) the fill is constructed with sound safety standards for public health, safety, and welfare; (e) the fill establishes a permanent shoreline; and (f) the applicant has valid title to the property.

Where a shoreline area is constructed on Commission-approved Bay fill, the Commission retains its Bay jurisdiction over that portion of the shoreline. The Commission may approve fill for shoreline protection, minor fill to improve shoreline appearance, for a water-oriented use, or to establish a permanent shoreline, provided that the fill satisfies all other provisions of the law.

2. **Extraction of Materials.** The Commission has the authority to require permits for proposals that involve the extraction of materials (e.g. dredging) in the Bay, certain waterways, salt ponds, and managed wetlands. The Bay Plan policies on dredging, in part, require dredging activities to be consistent with the Long Term Management Strategy for dredged materials in San Francisco Bay, establish the interagency Dredge Materials Management Office, encourage the beneficial reuse of dredged materials, and provide specific requirements for approving permits for dredging activities.

3. **Substantial Change in Use.** The Commission's regulations define a "substantial change in use" in salt ponds and managed wetlands as "any change in use including abandonment…[and] draining…." In other areas within the Commission's jurisdiction a substantial change in use is defined as "construction, reconstruction, alteration, or other activity, whether or not involving a structure…" and includes: a change in the category of use of a structure, in the intensity of use, an adverse affect on public access or future public access, or any subdivision of land pursuant to the Subdivision Map Act.

Salt Ponds and Managed Wetlands. The Commission's evaluation of fill projects in salt ponds and managed wetlands is limited to consistency with Section 66605 (c) through (g) of the McAteer-Petris Act. The requirement to weigh the public benefits and detriments of the fill does not apply to salt ponds and managed wetlands in the Commission's jurisdiction. Likewise, the test of whether fill in such areas could be sited on an alternative upland location is not required. Regarding permit requirements in salt ponds, the "extraction of materials" is limited to materials extracted for activities associated with salt production. Furthermore, the Commission's salt pond jurisdiction extends to dikes and protective structures that form the ponds.

Managed wetlands located in primary and secondary management areas of the Suisun Marsh are subject to additional policies in the Suisun Marsh Protection Plan and the Suisun Marsh Preservation Act of 1977. Those policies address a range of ecosystem and infrastructures issues, such as: water supply and quality, natural gas resources, utilities, transportation, and recreation.

The 100-Foot Shoreline Band. Within the Commission's shoreline band jurisdiction the Commission may only deny a permit for a project that: (1) fails to provide maximum feasible public access consistent with the project; or (2) conflicts with the use designated in a priority use area (McAteer-Petris Act Section 66632.4). Despite this limitation, the Commission is granted authority to require permits for projects in the 100-foot shoreline band for all of the reasons described above. However, the Commission can only condition a permit—require changes to the project—to provide maximum feasible public access and to be consistent with a priority use.

The Commission evaluates every permit application to ensure that project proposals provide the "maximum feasible public access consistent with the project." The Bay Plan policies on public access guide the Commission's evaluation of public access proposals. Those policies further provide guidance for public access and wildlife compatibility, and the siting and design of public access areas. The policies also require public access to be permanently guaranteed and maintained.

Priority use areas are for shoreline uses that are important to the region and require a shoreline location. They include, water-related industries, airports, wildlife refuges, and waterfront parks and beaches. Shoreline areas are designated as priority use areas in order to minimize the need to fill the Bay if land is unavailable for those uses.

Existing Bay Plan Policies Pertaining to Sea Level Rise. In 1989, the Commission updated the Bay Plan to address potential impacts from sea level rise, based on the best available information about sea level rise at the time. In 2000, the Commission amended the Bay Plan policies on Tidal Marshes and Tidal Flats. As a result of the 1989 and 2000 policy updates, the Bay Plan was amended to include the following policies:

- **Safety of Fills, Policy 4.** To prevent damage from flooding, structures on fill or near the shoreline should have adequate flood protection including consideration of future relative sea level rise as determined by competent engineers. As a general rule, structures on fill or near the shoreline should be above the wave run-up level or sufficiently set back from the edge of the shoreline so that the structure is not subject to dynamic wave energy. In all cases, the bottom floor level of structures should be above the highest estimated tide elevation. Exceptions to the general height rule may be made for developments specifically designed to tolerate periodic flooding.
- **Safety of Fills, Policy 6**. Local governments and special districts with responsibilities for flood protection should assure that their requirements and criteria reflect future relative sea level rise and should assure that new structures and uses attracting people are not approved in flood prone areas or in areas that will become flood prone in the future, and that structures and uses that are approvable will be built at stable elevations to assure long-term protection from flood hazards.
- **Tidal Marshes and Tidal Flats, Policy 5**. This policy provides specific requirements for the design and evaluation of tidal marsh restoration projects, which includes an analysis of the following: (a) the effects of relative sea level rise; (b) the impact of the project on the Bay's sediment budget; (c) localized sediment erosion and accretion; (d) the role of tidal flows: (e) potential invasive species introduction, spread, and their control; (f) rates of colonization by vegetation; (g) the expected use of the site by fish, other aquatic organisms and wildlife; and (h) site characterization.

Except in the case where a structure is proposed on Bay fill, the policies on safety of fills largely provide guidance to permit applicants and local governments on siting and designing projects to minimize impacts from flooding. The Commission's authority in the shoreline band to require changes in the siting and design of a project is limited to addressing impacts to present or future public access or the use of a priority use area for its designated purpose.

The Public Trust Doctrine and Takings. The public trust doctrine establishes a "public easement" over tidal and submerged lands that provides the public with rights to those lands for certain uses. The extent to which those public rights extend inland as sea level rises will impact how the Commission makes future regulatory decisions. The Commission's legal staff prepared a report to the Commission on the implications of rising sea levels on its public trust responsibilities and the relative role of "takings." The information below is summarized from the draft report.

The public trust doctrine dates back to Roman times and was imported to America from English common law. Traditionally, the public trust doctrine guaranteed public rights to navigable waters and submerged lands only for certain uses: fishing, navigation and commerce. Over time, each state developed and expanded its own public trust doctrine and the kinds of uses it protects. Through legislation and court decisions in California and other states the doctrine has expanded to include recreational uses and the preservation of lands in their natural state. Uses inconsistent with the public trust (non trust-related uses), are generally those that do not require waterfront locations like residential and non water-related commercial office uses.

The McAteer-Petris Act confers upon BCDC the authority to require "maximum feasible public access," ensure that public benefits of projects clearly exceed public detriments, and preserve water-oriented uses. These statutory provisions are direct expressions of the public trust doctrine.

A key element of the public trust doctrine is its effect on the regulation of private property. Government must compensate property owners under the Fifth Amendment of the U.S. Constitution if it "takes" private property for public uses. The "takings clause" limits the regulation of private property to protect natural resources and prevent environmental harm. However, the courts have held that government actions to enforce common law public easements such as the public trust doctrine, may be insulated from Fifth Amendment takings claims.

When government takes private property for a public purpose through eminent domain or condemnation, such as a highway or public works project, the property owner is compensated for the loss of value of the property. A taking by government regulation, or so-called "regulatory taking" may also occur when an agency permit allows a physical occupation without sufficient justification or renders a property valueless. However, the courts have been unable to establish a clear formula to determine when a regulatory taking occurs.

In summary, within the Commission's Bay, certain waterway, salt pond, and managed wetland jurisdiction, the Commission has clear, but, limited authority to address climate change, sea level rise and related impacts for projects that involve the placement of fill in all waters within the Commission's jurisdiction, including salt ponds and managed wetlands. This authority includes the ability to condition projects to be adaptable to sea level rise. For shoreline protection projects that involve Bay fill, the Commission has the authority to ensure that the fill is placed in a manner that minimizes harmful effects to the environment, which includes harmful effects from future flooding and harmful effects to waters within the Commission's jurisdiction.

Within the 100-foot shoreline band, the Commission's authority is limited to the provision of public access and the designation of priority use areas. This limitation is significant because it prevents the Commission from ensuring that development on the shoreline is sited and designed to avoid or minimize impacts from future flooding. The Commission can have an important advisory role to make recommendations on the siting and design of shoreline development to protect Bay resources and promote the wise development of the Bay shoreline.

BCDC's laws and policies create two other governance limitations. First, the Commission implements its authority on a permit-by-permit basis, and this limits the potential to analyze and address the cumulative impacts of individual projects, such as shoreline protection. Second, the focus of the McAteer-Petris Act and the Bay Plan on preventing the Bay from getting smaller creates an awkward policy framework from which to build a set of comprehensive climate change policies that sufficiently address the challenges of an expanding Bay.

The public trust doctrine is based on the historic value that the public has a right of access to the shorelines of navigable waters. The public trust formed the foundation for the McAteer-Petris Act and it is the background principle that can enable a number of adaptation strategies. In exercising the public trust, regulatory agencies must act carefully to avoid "taking" the rights of private property owners under the Fifth Amendment. There is no clear test to determine the extent to which a "public easement" can move inland as sea level rises without "taking" private property. This uncertainty about the migration of the public easement could limit the Commission's ability to adopt and implement policies that ensure long-term provision of shoreline public access.

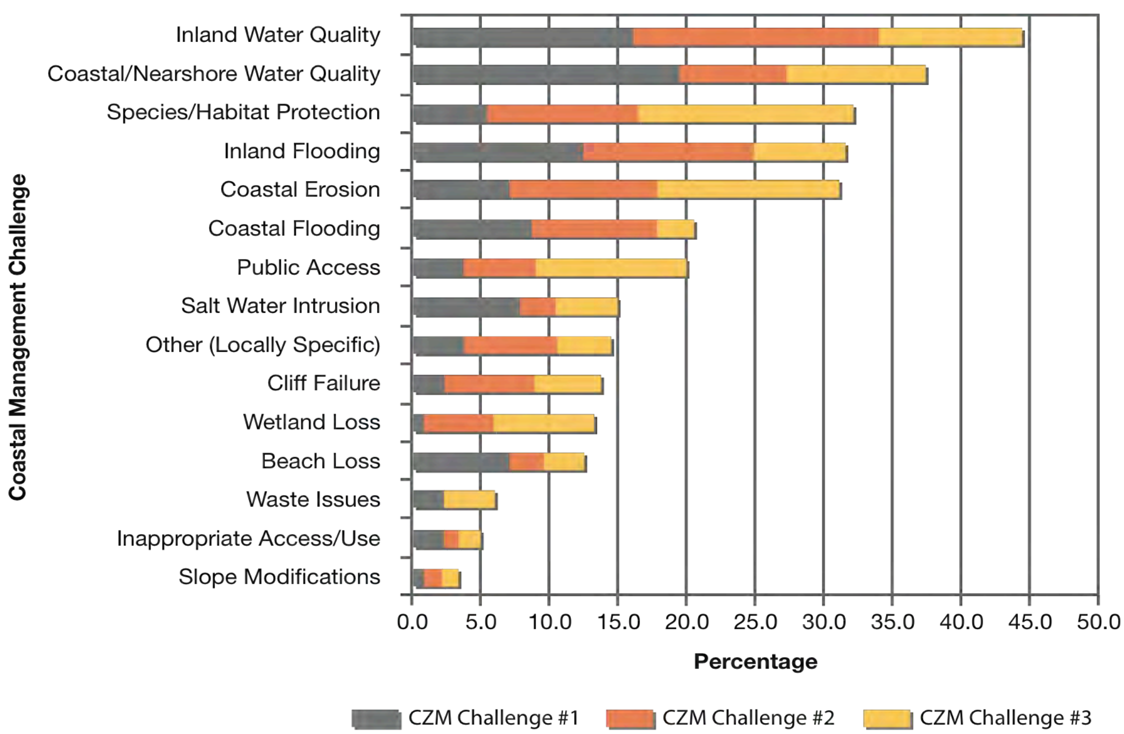
Needs Assessment for Local Jurisdictions

Local jurisdictions shoulder much of the responsibility for land use planning, flood management, water quality protection, and wastewater treatment, all of which will be affected by the Bay-related impacts of climate change. Cities and counties are granted "police powers" by the state, which allow them to protect the overall well-being of their communities (lives, health, and property) by enacting and enforcing ordinances and regulations. The state requires cities and counties to prepare and adopt comprehensive General Plans, consistent with state law, for physical development within their respective jurisdictions. In order to engage in effective adaptation planning, each local jurisdiction needs some level of knowledge about climate change that can be incorporated into ordinances, regulations and General Plans.

Statewide Survey. In 2006, the National Center for Atmospheric Research (NCAR) conducted a survey of local coastal managers in California in order to assess their information needs and their capacity to develop adaptation strategies. NCAR surveyed 299 municipal and county governments on the open coast and along the Bay shoreline. One of the key findings of the study was that coastal managers are already dealing with impacts of climate change. Eight of the top fifteen current challenges identified by coastal mangers can "directly or indirectly be related to climate variability and/or sea level rise (Moser and Tribia 2007(a))" (Figure 4.1).

Figure 4.1 Top Coastal Zone Management Challenges

Source: Moser and Tribbia 2007a



In the NCAR survey of local coastal managers, the topics that were assessed included, but were not limited to: level of knowledge of climate change impacts on coastal zones; information use and information needs related to coastal decision-making; and perceived barriers to adapt to climate change. Major findings from the NCAR study pertain directly to information needs and barriers to taking action:

- **Staffing and Resources.** Staffing is a major barrier to gathering and identifying climate change information. When asked to identify barriers to planning for climate change, 74 percent of respondents cited insufficient staff resources to analyze information; 60 percent identified lack of staff time to gather information and begin getting informed, and 46 percent mentioned lack of technical assistance from state or federal agencies (Moser and Tribia 2007a).
- **Information Accessibility and Relevance.** Vulnerability assessments are key to planning for climate change. Assistance in determining what is most at risk is a priority, especially "locally or regionally specific projections of particular changes in climate….[S]cientific information, even if uncertain, needs to be translated into management relevant variables or metrics (Moser and Tribbia 2007b)." While flooding scenarios are important, a permit analyst deals with rates of shoreline erosion, usually on a project-by-project basis. Projections are needed for timeframes that are relative to the life of a proposed project.
- **Information Location and Format.** For scientific information to be easily accessible and useful to local coastal managers, it should be processed into formats that are used by planners and permit analysts. (Moser and Tribia 2007b).

Although there are some differences in the issues encountered by coastal managers on the open coast and in the San Francisco estuary, qualitative data from a regional summit and a series of interviews conducted by BCDC are generally consistent with the NCAR findings.

In 2006, the Bay Area Air Quality Management District (Air District) hosted a regional climate change summit during which local jurisdictions identified areas where they need assistance. Although the discussion focused on greenhouse gas reductions, elements of the discussion provide important data regarding Bay Area local jurisdictions. Following the summit, the Air District staff identified needs and barriers common to Bay Area governments.

Similar to the findings discussed above, participants cited lack of knowledge as a barrier to confronting climate change and identified a specific desire for improving information accessibility through centralized information storage, such as a climate information clearinghouse or web portal. Participants also asked for guidelines for implementing climate change programs, such as sample ordinances. Participants identified lack of resources and competing internal priorities as major barriers to confronting climate change.

The data from the statewide survey and the Air District's summary of regional needs (BAAQMD 2006) provided BCDC with enough data to proceed with targeted, structured interviews with individuals from local jurisdictions (counties, cities, water districts, flood control districts, water quality agencies, and resource agencies). The purpose of the interviews was to assess common needs of local planners and resource managers within the Bay Area. BCDC's objectives in conducting additional interviews were to supplement and refine the existing data. Rather than replicate work that had already been completed, BCDC performed a qualitative analysis to integrate the existing data and apply lessons learned on the statewide level to the Bay Area.

Other common themes emerged from the interviews. A consistent comment was a request for a comprehensive regional model or set of projections of climate change impacts. The NCAR finding regarding the need for relevant information in a usable format was further echoed in the interviews. All three of these surveys of climate change planning at the local and regional levels concluded that planners and resource managers need better access to information. They would like to be able to turn to a web clearinghouse, or portal, for up-to-date information and downloads. Most interview participants want processed data in the form of GIS shapefiles or policy guidance documents. Only a few prefer unprocessed data that they can incorporate into in-house models. Regardless, a web portal seems to be a preferred distribution method.

The interviews further revealed distinctions between two types of local planners and resource managers: (1) local government land use planning departments; and (2) resource-based coastal managers, such as staff of flood control districts, water districts, water treatment facilities, and resource agencies. Local government land use planning departments were typically less knowledgeable about the Bay-related impacts of climate change than those in the second group or type. They were more likely than group two participants to identify their primary barrier as lack of financial resources and staff. The agencies they rely on for assistance and information were most often cited as the Federal Emergency Management Agency and the Army Corps of Engineers. Besides the obvious bias of being the interviewer and author, it is worth noting that BCDC was cited by almost all participants.

Utilities and others in the second group possessed a greater understanding of Bay-related impacts, especially pertaining to their individual purposes (e.g., water delivery, water treatment, etc.). The most commonly identified barrier was a lack of regional or site-specific information. Group two participants commonly rely on consultants to gather information or produce site-specific analysis.

Other governance vulnerabilities to climate change impacts exist because local governments operate within a policy environment that fails to provide incentives to proactively change their approaches to shoreline development. For example, Proposition 13 has forced local governments to rely more on new development for revenues from development fees and sales taxes, thus creating a fiscal disincentive to limit new shoreline development. Even where financial and policy incentives do encourage planning to improve disaster preparedness and mitigate the impacts of hazards, such as storm flooding, local governments are not required to consider future scenarios of climate change impacts in their planning efforts.

Summary and Conclusions

The Bay Area faces a range of vulnerabilities in its systems of governance that are evaluated here and summarized in Table 4.1. Governance vulnerabilities reduce the region's ability to adapt to sea level rise and other climate change impacts on the Bay and shoreline. A look at the region's overall governance system suggests that existing challenges to regional planning caused by the patchwork of federal, state, regional and local government authorities in the Bay region will be exacerbated by climate change impacts.

Table 4.1 Summary of Vulnerabilities in Bay Area Governance Systems

Governance	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	Adaptive Capacity	Vulnerability
BCDC	Limited jurisdiction and authority on the shoreline. Limited ability to address cumulative impacts through permit authority.	Inability to effectively address sea level rise and flooding in permits and planning efforts due to focus on preventing fill, and limited authority to deny permits on the shoreline. Uncertainty about changes to public easement due to sea level rise.	High – Bay and (most) shoreline projects designed to address sea level rise and flooding will require BCDC permit.	Low/Medium – Amendment of Bay Plan policies within existing law and policy framework can marginally improve BCDC's capacity to address sea level rise and flooding in some permits.	High

Continuation of Table 4.1 Summary of Vulnerabilities in Bay Area Governance Systems

Governance	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	Adaptive Capacity	Vulnerability
Local Governments	Already operating at capacity in terms of staff and funding resources.	Additional demands for staff and funding resources. Lack of information about impacts and guidance on adaptation planning.	High – Local governments will have major responsibilities for adaptation.	Medium – Have authority for conducting community adaptation planning, but lack incentives to change approaches to shoreline development.	High
Governance Landscape	Challenges to regional planning and implementa-tion of regional plans caused by patchwork of government agencies' authorities in the Bay Area.	Need for flexible and adaptive regional adaptation planning and management will be challenged by the patchwork of authority.	Medium – Adaptation requires coordinated regional planning and implementa-tion.	Medium - Region will be able to draw on experience from past regional planning efforts, but complexities of climate change create new, unfamiliar planning challenges.	Medium

BCDC faces governance limitations in its laws and policies. The Commission's jurisdiction on the shoreline is limited to 100 feet from the mean high tide line, and within this area BCDC's authority is limited to requiring maximum feasible public access and consistency with priority use areas. This limits the ability of the Commission to address issues like climate change and sea level rise in the shoreline band. The Commission's law is based on principles in the public trust doctrine, and the extent to which the public easement established by the public trust can move inland is undetermined. Furthermore, because BCDC implements its authority on a permit-by-permit basis, the Commission is limited in its ability to address the cumulative impacts of individual shoreline protection projects. The existing framework of BCDC's laws and policies that focus on preventing the Bay from shrinking is an overarching constraint to the Commission's ability to effectively plan for and adapt to climate change impacts.

Local governments and other management agencies, especially in cities and counties, have broad authority over shoreline land use. However, they lack policy incentives, resources and regional guidance for addressing climate change impacts in land use planning. To address these gaps, local governments need information about the Bay-related impacts of climate change that is region-specific and site-specific. The information should include a regional model that projects 50-100 years into the future or the expected "life of a project." The projections should be developed through a public, inclusive process in order to be widely accepted and used throughout the region. The system most commonly used by local governments for analyzing information is GIS. However, local planners and resource managers can benefit from guidance documents, such as sample ordinances.

Lack of staff and adequate financial resources are the primary barriers to planning for coastal impacts of climate change, both statewide and in the Bay Area. Any assistance to local governments and public management agencies must address this issue either by providing more staff and financial resources or by providing information that is easily integrated into existing operations, planning tools, guidance documents, and planning processes (e.g., general plan updates).

CHAPTER 5
Adaptation Strategies

California is a leader in working to reduce greenhouse gas emissions. However, no matter how successful these efforts are, the state needs to plan for the inevitable impacts of climate change caused by past emissions, including sea level rise.

Some of California's most highly valued cities and natural areas are in low-lying lands around San Francisco Bay. Critical Bay Area assets may be lost as sea level rises. The most imminent threat facing the region is more frequent and extreme flooding of residential areas, which make up 50 percent of the lands potentially affected by sea level rise and storms. Managing the threats to Bay resources and shoreline development from sea level rise will be one of the defining challenges we face in the 21st century.

Communities that fail to plan for these changes will find themselves responding to emergencies with increasing frequency (Pacific Council 2010). Reacting to crises without taking proactive steps to prepare is likely to have devastating societal, economic and environmental costs. Therefore, the region should develop an adaptation framework upon which to build as science advances, innovative technologies and management strategies emerge, ecosystems change, and lessons are learned from successes and failures.

This chapter discusses issues to consider when planning for climate change adaptation, and presents a decision-making framework that can increase adaptive capacity of the Bay ecosystem and the built shoreline environment. This chapter also presents staff recommendations to the Commission for updating the Bay Plan to address climate change, and facilitating a regional climate change strategy that includes strengthening agency partnerships and assisting local governments.

Adaptation Planning Considerations

A prudent approach to addressing climate change impacts is to use a robust planning framework and active stakeholder participation to select an appropriate set of responses for a specific site, community or subregion of the Bay Area, prioritize them, and implement them over time, incorporating lessons learned into the process. The following issues should be considered when developing adaptation strategies.

Adaptation Planning Strategies. To make the best use of the limited resources available to local governments, climate change planning can be "mainstreamed" into existing planning efforts (Luers and Moser 2006, USEPA 2008, Moser and Tribbia 2007). For example, some Bay Area cities have assessed climate change impacts in the process of updating their General Plans, and adopted adaptive land use policies to reduce or prepare for these impacts.

Adaptation strategies that address immediate or ongoing concerns while reducing future risks (often called "no regrets" or "low regrets" strategies) can readily be integrated into current planning efforts (Luers and Moser 2006). Water conservation is an example of a potential no regrets strategy that mitigates greenhouse gas emissions by reducing the needed for treatment and transport of water, and improves resilience to climate change impacts on water supply. Another example is the restoration of tidal marshes to provide open space, natural habitat and flood protection.

Other strategies can be used to mainstream adaptation efforts, for example incorporating actions to address future climate change into routine efforts, such as repair and maintenance projects, without incurring substantial additional costs at the time of the upgrade (Luers and Moser 2006). For example, to reduce possible flood damage costs, expensive home appliances, such as furnaces, water heaters, clothes washers and dryers, can be relocated to an upper story at the time of replacement. To the extent that these strategies can be identified, they should be implemented immediately.

Box 5.1 Adaptive Management in the South Bay Salt Pond Restoration Project

Adaptive management is a widely recognized approach to addressing uncertainty in resource management. It is often characterized as "learning by doing." An adaptive management approach takes account of uncertainty in the design and implementation of resource management policy and maximizes the opportunity to learn from management actions. Monitoring the success of our management actions in both the Bay ecosystem and along the natural and built shoreline is the fundamental process for reducing uncertainty and implementing effective management. The adaptive management process links values, science, and managers in the decision-making process and throughout project implementation.

The South Bay Salt Pond Restoration Project (Project) is based on an Adaptive Management Plan (Plan). The Plan creates a framework for achieving project objectives through learning from restoration and management actions by monitoring restoration progress and gradually reducing scientific and social uncertainties.

The Project's goal is to restore and enhance over 15,000 acres (23 square miles) of wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation. The Project seeks a balance between restoring wetland habitat and maintaining existing pond habitat, with alternative scenarios ranging from 50 percent each of wetlands and ponds to 90 percent wetlands and 10 percent ponds. Project participants identified eight key uncertainties that could make meeting the project objectives difficult. These included sediment dynamics, bird response to changing habitats, non-avian species responses, mercury issues, invasive and non-native species, water quality, public access and wildlife, and social dynamics. The overarching uncertainty of global climate change is incorporated, de facto, into each of the specific key uncertainties.

The Project participants agreed that, due to the many uncertainties, the mix of habitats that will optimally meet the project objectives—including the amount of tidal restoration and its location—cannot be predicted at this time. Therefore, the project will be implemented and evaluated in phases and will use adaptive management as the process for determining how far the system can move toward full tidal action and associated tidal habitats, while still meeting the project objectives (Trulio et al. 2007).

The Project is led by the U.S. Fish and Wildlife Service, California Department of Fish and Game, Conservancy, Santa Clara Valley Water District, and Alameda County Flood Control and Water Conservation District.

Adaptive Management. Adaptation planning and implementation should be based on the principles of adaptive management so that they take into account uncertainty and maximize the opportunities to learn from management actions. (See Box 5.1.) This requires careful monitoring, which takes time, financial resources, and scientific and technical expertise. Although advances in science have led to better climate change projections, there is still a large degree of uncertainty about future rates of sea level rise. There is also uncertainty about climate change impacts and the effectiveness of adaptation measures. Scientific and technical knowledge will continue to develop at a rapid rate, requiring planners and resource managers to create flexible management strategies and identify triggers for changing course when necessary.

Ecosystem-Based Management. Shoreline planning will become increasingly challenging as the line between uplands and baylands becomes more dynamic, thereby requiring a creative planning approach that integrates natural resource management and land use planning. Ecosystem-based management (EBM) integrates human needs and systems into marine or estuarine environmental management, bringing stakeholders into decision-making processes, and providing direction through those processes. EBM also recognizes the need for iterative approaches to managing complex systems, i.e., adaptive management. EBM can provide a portfolio of approaches and the online tools to support these approaches, ranging from tools for stakeholder outreach to mapping tools.

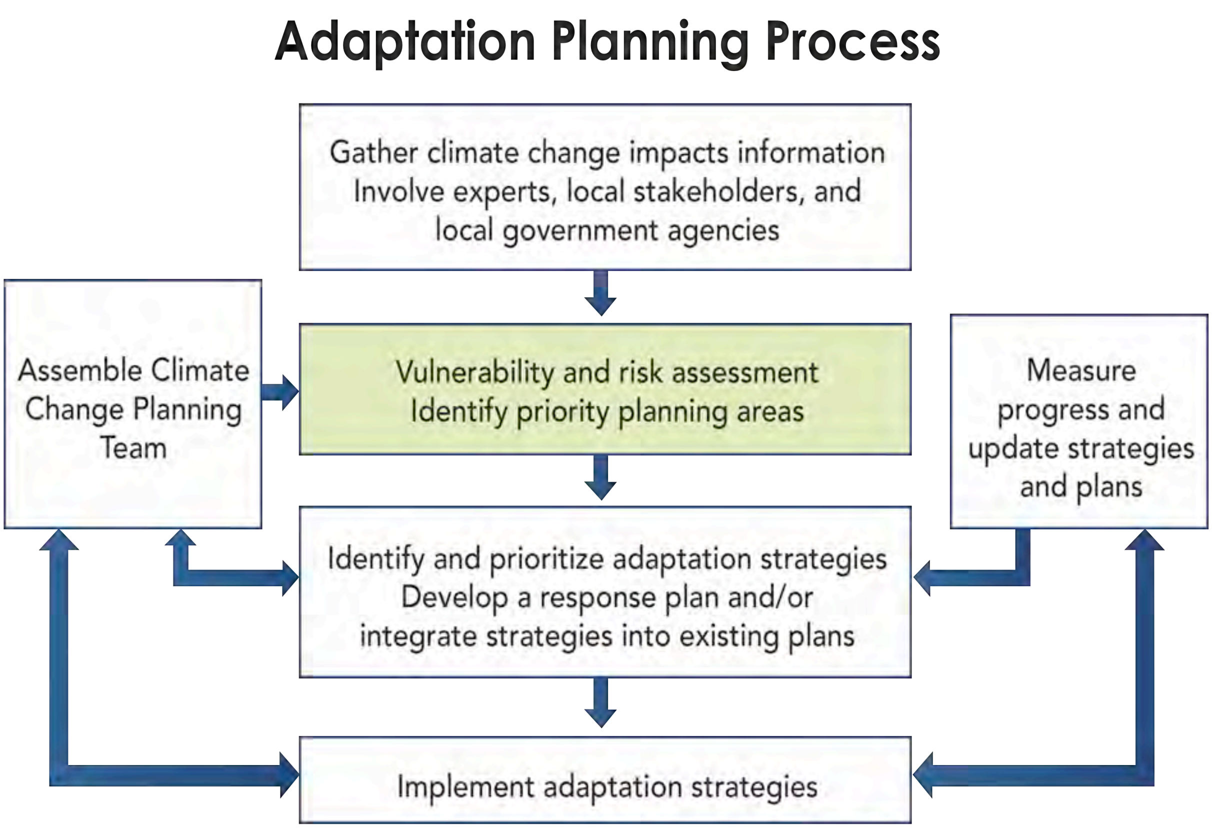
Integrating Mitigation and Adaptation. While mitigation lessens future impacts by taking steps to reduce greenhouse gas emissions and capture greenhouse gases, adaptation makes communities, infrastructure and the natural environment more resilient to the impacts from emissions. Mitigation has traditionally been at the forefront of the global climate change dialogue as the world attempts to avoid further altering the Earth's atmosphere. Adaptation reduces the vulnerability of natural systems and human communities to existing or predicted climate change impacts.

Integrating mitigation and adaptation planning can reduce inefficiencies and potential conflicts while providing greater protection. For example, conserving and restoring tidal marsh provides flood protection and achieves mitigation by sequestering carbon. In addition, increased habitat will be available to climate-stressed species. Another example is the siting of new sustainable communities outside of current and future floodplains. Development of sustainable communities, in which housing is located near jobs and public transit, reduces greenhouse gas emissions from driving, while focusing such development in upland areas is one means of reducing its vulnerability to sea level rise.

Adaptation Planning Framework

Most adaptation planning frameworks include a few key steps: identifying a planning area and scoping of potential climate change impacts, conducting vulnerability and risk assessments, developing and implementing an adaptation plan, and conducting monitoring and adaptive management. (See Figure 5.1.) BCDC developed the framework used in this report based on its review of several examples. The analysis in this report provides the basis for the Commission to identify ways to promote adaptation within BCDC's limited jurisdiction and to recommend that a collaborative process be undertaken in partnership with other regional agencies, local governments and stakeholders to develop a regional strategy to deal effectively with sea level rise and other adaptation challenges in the Bay Area. The iterative nature of this framework will allow BCDC to continually incorporate new scientific knowledge and analytical tools as they are developed.

Figure 5.1. Climate Change Adaptation Planning Model



Vulnerability and Risk. A vulnerability assessment helps communities identify the resources—the people, places, buildings, infrastructure, and natural areas—that are most susceptible to climate change impacts. A risk assessment builds on the information developed in a vulnerability assessment by describing the likelihood that specific impacts will occur and the consequences those impacts would have for the community. Together, these assessments are important steps in an adaptation planning process that can help communities define key issues related to climate change impacts, determine how best to respond, and decide when to take action.

In a vulnerability assessment, communities examine how people, property, and resources are susceptible to the types of impacts associated with climate change. They begin by reviewing information about global and regional climate change trends to identify locally relevant impacts such as more frequent flooding and inundation due to sea level rise. Then, to better understand these impacts, the community can use its knowledge of existing resources and stressors to determine how and when it could be sensitive to change. Last, the community can determine its capacity to cope with these impacts now and into the future.

In a risk assessment, communities combine information about the economic, social, legal, and ecological consequences of specific impacts with the likelihood that those impacts will occur in order to set priorities. A highly likely impact (such as higher daily tides) that has considerable negative consequences (such as inundation of critical transportation infrastructure or groundwater intrusion into a community's water supply) is a high-risk impact that should be elevated to an adaptation planning priority.

In this report, a vulnerability analysis was conducted to understand the effects of climate change on San Francisco Bay and the shoreline. This effort began with identifying three systems that encompass the broad scope of climate change planning considerations: shoreline development, the Bay ecosystem, and governance. Current challenges facing each system were identified to provide a qualitative assessment of adaptive capacity and identify where challenges will be exacerbated with climate change. Two climate change scenarios were selected to evaluate the impacts on the Bay and shoreline. Where possible, quantitative analysis was provided to illuminate the scale of the impact, such as the size of an area or population affected. In the discussion on governance, current challenges were identified in terms of the limits of the Commission's jurisdiction and authority and the needs of local governments.

Adaptation Strategies for San Francisco Bay and its Shoreline

Effective adaptation to address the climate change impacts identified in the vulnerability analysis will require action by a wide range of organizations and individuals. The ocean and coastal resources chapter of the 2009 California Climate Adaptation Strategy provides some guiding principles for making difficult decisions about maintaining and enhancing natural resources while protecting development and public safety:

- Protect public heath and safety and critical infrastructure.
- Protect, restore, and enhance ocean and coastal ecosystems, on which our economy and wellbeing depend.
- Ensure public access to coastal areas and protect beaches, natural shoreline, and park and recreational resources.
- Plan and design new development and communities so they will be sustainable over the long term in the face of climate change.
- Facilitate adaptation of existing development and communities to reduce their vulnerability to climate change impacts over time.
- Begin now to adapt to the impacts of climate change.

The Bay Area will need to select adaptation strategies to address key vulnerabilities that occur at various scales and timeframes. In the near term, the Commission has limited legal authority to ensure that sea level rise is taken into consideration in the design of projects within BCDC's jurisdiction. In the long run, the Commission can help facilitate a collaborative process to develop a regional strategy to deal effectively with sea level rise and integrate climate change mitigation and adaptation planning in the Bay Area. The following sections focus on adaptation strategies that the Commission can undertake and encourage through amendment of the Bay Plan to address the issues identified in the vulnerability assessment and discuss the Commission's role in facilitating the development of a regional strategy.

1. Shoreline Development

The heavily developed Bay shoreline supports multiple, competing uses, including residential, commercial, industrial, and recreational uses. Shoreline development that is now potentially exposed to a 100-year high water event could be exposed to the average high tide by mid-century. Approximately half of the development potentially at risk is residential. Large commercial and industrial areas will also be at risk of flooding or permanent inundation, especially in San Francisco, Silicon Valley, and Oakland. Ports, airports, water-related industry, wastewater treatment plants, waterfront parks and beaches, trails, and other important facilities are all at risk. In addition, many of the major roads, highways and railroads within the region may be significantly impacted by sea level rise and extreme flooding events.

Critical public infrastructure and essential development on the Bay shoreline will require protection to prevent flooding and permanent inundation from sea level rise, yet protecting all developed areas may prove to be financially infeasible or ecologically destructive. In the long-term, the region needs to engage in an open and vigorous public dialogue to make the difficult decisions about where and how existing development should be protected and infill development encouraged, where new development should or should not be permitted, and where existing development should eventually be removed to allow the Bay to migrate inland.

The Commission has limited authority to address climate change, sea level rise and related impacts for projects that involve the placement of fill in the Bay. Within the 100-foot shoreline band, the Commission's authority is limited to requiring maximum feasible public access and land use consistency within priority use areas. This limitation prevents the Commission from requiring that development on the shoreline is sited and designed to avoid or minimize impacts from future flooding due to sea level rise. However, the Bay Plan can be amended to incorporate the following objectives for achieving resilience to flooding when planning and designing shoreline projects.

Risk Assessments and Adaptive Management Plans. Risk assessments should be conducted for larger shoreline projects and updates of plans addressing shoreline areas vulnerable to flooding. These assessments should use the best available science-based projection for sea level rise at the end of the century and should identify all types of potential flooding, degrees of uncertainty, consequences of defense failure, and risks to existing habitat from proposed flood protection devices. Shoreline plans and larger shoreline projects should be designed to be resilient to a mid-century sea level rise projection, and if it is likely the project will remain in place longer than mid-century, an adaptive management plan should be prepared to address the long-term impacts. To be cost-effective risk assessments should not be prepared for projects that do not significantly increase overall risks to public safety, such as small projects, repairs of existing facilities, interim uses and public parks.

Evaluating Project Proposals. Large projects proposed in vulnerable areas should be evaluated on a case-by-case basis to determine the project's public benefits, resilience to flooding, and capacity to adapt to climate change impacts. Projects with regional benefits, such as environmental remediation, critical public infrastructure, infill that concentrates employment or housing near transit service, and natural resource restoration or enhancement, should be encouraged if their regional benefits and their advancement of regional goals outweigh the risks from flooding. Projects that do not negatively impact the Bay and do not increase risks to public safety, such as repairs, small projects, interim uses and public parks, should also be encouraged.

Safety of Fills. Flood damage to fills and shoreline areas can result from a combination of sea level rise, storm surge, rainfall, high tides, and winds blowing onshore. The most effective way to prevent such damage is to locate projects and facilities above the 100-year flood level that takes future sea level rise into account during the expected life of the project. Adequate measures should be provided to prevent damage from sea level rise and storm activity that may occur on fill or near the shoreline over the expected life of a project. The Commission may approve fill that is needed to provide flood protection for existing projects and uses, as long as the fill is the minimum necessary and serves a water-oriented use.

New projects on the shoreline should either to either be set back from the edge of the shore so that the project will not be subject to dynamic wave energy, be built so the bottom floor level of structures will be above a 100-year flood elevation that takes future sea level rise into account for the expected life of the project, be specifically designed to tolerate periodic flooding, or employ other effective means of addressing the impacts of future sea level rise and storm activity. Rights-of-way for levees or other structures protecting inland areas from tidal flooding should be sufficiently wide on the upland side to allow for future levee widening to support additional levee height so that no fill for levee widening is placed in the Bay.

Shoreline Protection. Critical public infrastructure and essential development on the Bay shoreline will require protection to prevent inundation and flooding from sea level rise. BCDC's existing shoreline protection policies focus on protecting the shoreline from erosion. Due to sea level rise, the Commission needs amended policies to enable it to address shoreline flooding as well as erosion. Shoreline protection can be structural, natural, or a combination of both. Choosing the appropriate form of shoreline protection—one that both protects public safety and minimizes ecosystem impacts—is critically important.

New shoreline protection projects and the maintenance or reconstruction of existing projects and uses should be allowed if the project is necessary to provide flood or erosion protection for (a) existing development, use or infrastructure, or (b) proposed development, use or infrastructure that is consistent with other Bay Plan policies. The type of the protective structure should be appropriate for the project site, the uses to be protected, and the erosion and flooding conditions at the site. Knowledgeable professionals, such as civil engineers experienced in coastal processes, should participate in the design.

Addressing the impacts of sea level rise and shoreline flooding may require large-scale flood protection projects, including some that extend across jurisdictional or property boundaries. Coordination with adjacent property owners or jurisdictions to create contiguous, effective shoreline protection is critical when planning and constructing flood protection projects. Failure to coordinate may result in inadequate shoreline protection (e.g., a protection system with gaps or one that causes accelerated erosion in adjacent areas). Each project should be integrated with current or planned adjacent shoreline protection measures.

Shoreline protection projects should include provisions for nonstructural methods such as marsh vegetation and integrate shoreline protection and Bay ecosystem enhancement, using adaptive management, whenever feasible. Along shorelines that support marsh vegetation, shoreline protection projects should establish transitional upland vegetation as part of the protective structure whenever feasible. Shoreline protection projects should be properly designed and constructed to prevent significant impediments to physical and visual public access. The adverse impacts to natural resources and public access from new shoreline protection should be avoided. Where adverse impacts cannot be avoided, habitat mitigation or alternative public access should be provided.

High Water Level Metric. The Bay Plan policies should be amended to use a more appropriate measure of high water levels. Staff considered three alternative measures that could be used as a base high water level metric on to which sea level rise can be added when designing projects to be resilient or adaptable to climate change: (1) highest estimated tide (2) Base Flood Elevation (BFE) provided by the Federal Emergency Management Agency (FEMA); and (3) a case-by-case determination of the appropriate high-water metric, based on individual project characteristics.

BCDC's existing Bay Plan policies require all projects within the Commission's jurisdiction to be built above the highest estimated tide and wave run up levels for the life of the project. The highest estimated tide (NGVD) with an expected recurrence interval of 100 years is available for sites around the Bay, based on a 1984 Army Corps of Engineers analysis of the highest yearly tide level observed at the Presidio for the period from 1855-1983. Since the highest estimated tide is based on an extrapolation of data from one tide gauge (the Presidio), and is based on the historic record, this metric has limited utility for producing accurate estimates of future conditions in the entire estuary. In addition, site-specific conditions such as wave run up and watershed contributions from runoff are generally underestimated by this metric. The case-by-case approach creates a great deal of uncertainty regarding the appropriate metrics to be used for project evaluations, and would create difficulties for permit applicants and their consultants when analyzing project vulnerabilities and developing resilient designs and adaptation plans.

Representatives of the Bay Area Flood Protection Agencies Association (BAFPAA), the Bay Area's regional flood control experts, recommended that BFE provided on maps published by FEMA be used, because: (1) BFE reflects 100-year flood stillwater elevations plus wave run up; (2) FEMA wave run up values are conservative; (3) interpolation between nearest published elevations is an acceptable way to estimate elevations for locations that do not have a published BFE (BAFPAA 2010). Therefore, the Bay Plan should be revised to recommend using the estimated 100-year flood elevation that takes sea level rise into account (i.e., BFE plus sea level rise) in risk assessments, in the design of projects on fill or near the shoreline, and in the design of shoreline protection projects.

Public Access. Accelerated flooding from sea level rise and storm activity will severely impact existing shoreline public access, resulting in temporary or permanent closures. Periodic and consistent flooding would increase damage to public access areas, which can then require additional fill to repair, raise maintenance costs, and cause greater disturbance and displacement of the site's natural resources. Risks to public health and safety from sea level rise and shoreline flooding may require new shoreline protection to be installed or existing shoreline protection to be modified, which may impede physical and visual access to the Bay. Flooding from sea level rise and storm activity increases the difficulty of designing public access areas (e.g., connecting new public access that is set at a higher elevation or located farther inland than existing public access areas). Public access should be sited, designed, managed and maintained to avoid significant adverse impacts from sea level rise and shoreline flooding. Any public access provided should either be designed to remain viable in the event of future sea level rise or flooding, or equivalent access should be provided nearby.

2. Bay Ecosystem

The Bay ecosystem is already stressed by human activities that lower its adaptive capacity, such as diversion of freshwater inflow and conversion of tidal wetlands. These activities have resulted in losses in critical estuarine functions, loss of habitat extent, and compromised water quality. Climate change will further alter the ecosystem by inundating or eroding wetlands and transitional habitats, changing sediment dynamics, altering species composition, raising the acidity of Bay waters, changing freshwater inflow or salinity, altering the food web, and impairing water quality, all of which may impair the system's ability to rebound and function. Changes in salinity from reduced freshwater inflow will affect fish, wildlife and other aquatic organisms in intertidal and subtidal habitats. Further inundation of tidal wetlands is potentially devastating to the San Francisco Bay ecosystem. Moreover, further loss of tidal wetlands will increase the risk of shoreline flooding.

Tidal Marshes and Tidal Flats. The highly developed Bay shoreline constrains the ability of tidal marshes to migrate landward, while the declining sediment supply in the Bay reduces the ability of tidal marshes to grow upward as sea level rises. The loss of transitional habitats, such as the upland ecotone, to erosion or inundation would devastate a diverse number of species, including California clapper rail and the salt marsh harvest mouse who use these habitats for refuge during high tides.

Key issues that resource managers must address regarding adaptation planning for tidal marshes and tidal flats include: protecting undeveloped areas with current or potential habitat value, identifying opportunities for tidal wetlands and tidal flats to migrate landward by maintaining sufficient upland buffer areas, developing and planning for natural flood protection, managing and maintaining adequate volumes of sediment for marsh restoration and preservation, and updating regional ecosystem targets to take climate change into consideration.

Some undeveloped low-lying areas that are at risk of shoreline flooding contain important habitat or provide opportunities for habitat enhancement. Preservation or restoration of tidal habitat in these areas could help offset the loss of tidal habitat due to sea level rise in other areas.

Buffers are areas established adjacent to a habitat to reduce the adverse impacts of surrounding land use and activities. Buffers around tidal wetlands could minimize loss of habitat from shoreline erosion resulting from accelerated sea level rise and allow tidal habitats to move landward.

Nonstructural shoreline protection methods, such as tidal marshes, can provide effective flood control. In some instances, it may be possible to combine habitat restoration, enhancement or protection with structural approaches to provide protection from flooding and control shoreline erosion, thereby minimizing the shoreline protection project's impact on natural resources.

Sedimentation is an essential factor in the creation, maintenance and growth of tidal marsh and tidal flat habitat. However, scientists have observed that the volume of sediment entering the Bay annually is declining. As sea level rises, an inadequate sediment supply could adversely affect the sustainability of tidal wetland restoration projects. Human actions, such as dredging, disposal, ecosystem restoration, and watershed management, can affect the distribution and amount of sediment available to sustain and restore wetlands.

The Baylands Ecosystem Habitat Goals report provides a regional vision of the types, amounts, and distribution of wetlands and related habitats that are needed to restore and sustain a healthy Bay ecosystem, including restoration of 65,000 acres of tidal marsh. These recommendations were based on conditions of tidal inundation, salinity, and sedimentation in the 1990s. While achieving the regional vision would help promote a healthy, resilient Bay ecosystem, global climate change and sea level rise are expected to alter ecosystem processes in ways that require new, regional targets for types, amounts, and distribution of habitats.

The Bay Plan can be amended to incorporate the following objectives for achieving environmental sustainability in the face of climate change. Habitat preservation and enhancement should be encouraged in undeveloped areas that are both vulnerable to future flooding and currently sustain significant habitats or species, or possess conditions that make the areas especially suitable for ecosystem enhancement. Each ecosystem restoration project should include an appropriate buffer, where feasible, between shoreline development and habitats to protect wildlife and provide space for marsh migration as sea level rises. Shoreline protection projects should include provisions for establishing marsh and transitional upland vegetation as part of the protective structure, wherever feasible. Comprehensive Bay sediment research and monitoring should be supported to understand sediment processes necessary to sustain and restore wetlands. Monitoring methods should be updated periodically based on current scientific information. Regional ecosystem targets should be updated periodically to guide conservation, restoration, and management efforts that result in a Bay ecosystem resilient to climate change and sea level rise.

3. Governance

Managing the threats to the Bay and shoreline development from sea level rise will create major challenges for the governance system in the Bay Area. Numerous government agencies create a patchwork of authority that requires a strong, but flexible network of partnerships. As mentioned above, failure to coordinate across property lines and jurisdictional boundaries could result in gaps in the shoreline protection system and accelerated erosion in adjacent areas. An uncoordinated approach to flood protection could also result in cumulative adverse impacts to tidal marshes and other important habitats. Conversely, coordinated regional planning will be essential to gaining political support for regional funding for flood protection and ecosystem restoration programs.

Regional Strategy. The Commission was created in 1965 because haphazard filling was shrinking the Bay. Although this issue has been successfully addressed, climate change and accompanying sea level rise are causing the Bay to expand at an increasing rate. Sea level rise has put shoreline development and habitats throughout the region at risk, and creating the need for a comprehensive regional strategy that addresses this challenge.

Developing a regional strategy to address sea level rise will help the Bay Area avoid the pitfalls of the piecemeal approach and capitalize on the opportunity to continue to lead the nation in climate change adaptation. The goal of this strategy should not be to restore the Bay to historic conditions. Instead, the strategy should describe a vision for resilient communities and adaptable natural areas around a dynamic and changing Bay that will have different sea level elevations, different salinity levels, different species and different chemistry than the Bay has today. The strategy should embrace an adaptive management strategy aimed at putting conditions in place that can respond in a desired way to changes that will come about in the future as a result of climate change. The task sounds daunting, but for over 60 years, the Bay Area has pioneered regional action regarding difficult decisions and environmental hazards (See Box 5.2.).

This new strategy should draw from the lessons learned during the formulation and implementation of BCDC's existing, highly effective San Francisco Bay Plan, particularly the plan's goal of balancing conservation and development. The new strategy should integrate ecosystem-based adaptive management principles to ensure that future development, shoreline retreat, flood protection and wetland enhancement strategies are coordinated to achieve a vibrant, healthy Bay co-existing with sustainable communities around the Bay.

The regional strategy should also build on the FOCUS program initiated by the Association of Bay Area Governments and the Metropolitan Transportation Commission to promote a more compact Bay Area land use pattern. In consultation with local governments, the FOCUS program has identified Priority Development Areas (PDAs) for infill development in the Bay Area. These PDAs, along with other sites, are anticipated to be key components of the Bay Area's Sustainable Communities Strategy that will be adopted and periodically updated pursuant to SB 375.

One of the Commission's objectives in adopting climate change policies is to facilitate implementation of the Sustainable Communities Strategy. Some shoreline areas that are already improved with public infrastructure and private development that have regionally significant economic, cultural or social value, and can accommodate infill development, including some PDAs, are also vulnerable to shoreline flooding. In such cases, the regional goal of concentrating housing and job density near transit conflicts with the goal of minimizing flood risk by avoiding development in low-lying areas vulnerable to flooding. Reconciling these different worthy goals and taking appropriate action requires weighing competing policy considerations and is best accomplished through a collaborative process involving diverse stakeholders, similar to that being undertaken to develop the Sustainable Communities Strategy.

The Commission, in collaboration with the Joint Policy Committee, other regional, state and federal agencies, local governments, and the general public, should formulate a regional sea level rise adaptation strategy for protecting critical developed shoreline areas and natural ecosystems, enhancing the resilience of Bay and shoreline systems and increasing their adaptive capacity. Ideally, the regional strategy will determine where and how existing development should be protected and infill development encouraged, where new development should and should not be permitted, and where existing development should eventually be removed to allow the Bay to migrate inland.

To develop a regional strategy, the Commission could amend the Bay Plan policies to recommend that:

- The regional strategy incorporate an adaptive management approach;

Box 5.2 Regional Problems, Regional Solutions: A History of Regional Action on Public Safety and Environmental Issues in the Bay Area.

The Bay Area Air Quality Management Districts' website describes how the region came together to address poor air quality (http://www.baaqmd.gov/50th/index.html). When America's fighting forces came home from World War II, many settled in the last place they saw before going overseas--California's embarkation ports. Here, they went to school on the GI Bill, married, bought homes, and began the biggest "baby boom" the world has ever seen. With this population growth came expanding urban areas, shrinking agricultural lands, and the building of housing developments farther from urban centers. For the first time in many years, cars were available, affordable, and now necessary to reach the new suburbs.

The term "smog," originally coined to describe the combination of smoke and fog prevalent in London, soon became a household word in the Bay Area, with open fires from dumps and wrecking yards burning 24 hours a day. Initially measured in levels of eye irritation, air pollution was becoming a major problem, causing significant damage to Bay Area crops.

In 1946, the California Legislature enacted the first air pollution control law authorizing the formation of county air pollution control districts. Los Angeles County opened the first air pollution control office in early 1947 and Santa Clara County followed soon after. However, by 1950, it was evident that pollution overflowed political boundaries, and that a single-county district was not the answer for the Bay Area. In 1955, the Bay Area Air Pollution Control Law was adopted, establishing the Bay Area Air Pollution Control District as the first regional air pollution control agency in the nation.

Alarmed by the fact that between 1850 and 1960 an average of four square miles of the Bay were filled each year, in 1961 citizens in the Bay Area formed the Save San Francisco Bay Association, now called Save the Bay. At the urging of this organization, state legislation--the McAteer-Petris Act--was passed in 1965 to establish the San Francisco Bay Conservation and Development Commission (BCDC) as a temporary state agency. The Commission was charged with preparing a plan for the long-term use of the Bay and regulating development in and around the Bay while the plan was being prepared.

The San Francisco Bay Plan, which was completed in January 1969, includes policies on issues critical to the wise use of the Bay ranging from ports and public access to design and transportation. The Bay Plan also contains maps of the entire Bay which designate shoreline areas that should be reserved for water-related purposes like ports, industry, public recreation, airports, and wildlife refuges.

- The strategy be consistent with the goals of SB 375 and the principles of the California Climate Adaptation Strategy;
- The strategy be updated regularly to reflect changing conditions and scientific information and include maps of shoreline areas that are vulnerable to flooding based on projections of future sea level rise and shoreline flooding;
- The maps be prepared under the direction of a qualified engineer and regularly updated in consultation with government agencies with authority over flood protection; and
- Particular attention be given to identifying and encouraging the development of long-term regional flood protection strategies that may be beyond the fiscal resources of individual local agencies.

The Commission could also recommend that the entities that formulate the regional strategy consider the following strategies and goals:

- Advance regional public safety and economic prosperity by protecting: (i) existing development that provides regionally significant benefits; (ii) new shoreline development that is consistent with other Bay Plan policies; and (iii) infrastructure that is crucial to public health or the region's economy, such as airports, ports, regional transportation, wastewater treatment facilities, major parks, recreational areas and trails;
- Enhance the Bay ecosystem by identifying areas where tidal wetlands and tidal flats can migrate landward; assuring adequate volumes of sediment for marsh accretion; identifying conservation areas that should be considered for acquisition, preservation or enhancement; developing and planning for flood protection; and maintaining sufficient transitional habitat and upland buffer areas around tidal wetlands;
- Integrate the protection of existing and future shoreline development with the enhancement of the Bay ecosystem, such as by using feasible shoreline protection measures that incorporate natural Bay habitat for flood control and erosion prevention;
- Encourage innovative approaches to sea level rise adaptation;
- Identify a framework for integrating the adaptation responses of multiple government agencies;
- Integrate regional mitigation measures designed to reduce greenhouse gas emissions with regional adaptation measures designed to address the unavoidable impacts of climate change;
- Address environmental justice and social equity issues;

- Integrate hazard mitigation and emergency preparedness planning with adaptation planning by developing techniques for reducing contamination releases, structural damage and toxic mold growth associated with flooding of buildings, and establishing emergency assistance centers in neighborhoods at risk from flooding;
- Advance regional sustainability, encourage infill development and job creation, and provide diverse housing served by transit;
- Encourage the remediation of shoreline areas with existing environmental degradation and contamination in order to reduce risks to the Bay's water quality in the event of flooding;
- Support research that provides information useful for planning and policy development on the impacts of climate change on the Bay, particularly those related to shoreline flooding;
- Identify actions to prepare and implement the strategy, including any needed changes in law; and
- Identify mechanisms to provide information, tools, and financial resources so local governments can integrate regional climate change adaptation planning into local community design processes.

Adaptation Tools for Local Government. Local governments and other management agencies with broad authority over shoreline land use and flood risk mitigation will play important roles in developing and implementing a regional strategy for sea level rise adaptation. Until a regional strategy is developed, local governments will have the primary responsibility for addressing sea level rise, but they often lack adequate information, financial and technical resources, and policy guidance. Assistance to local governments and public management agencies can provide staff and financial resources and/or information that can easily be integrated into existing operations, planning tools, guidance documents, and planning processes.

Local governments can use a variety of tools to implement climate change adaptations strategies. Regulatory, market-based and spending tools such as those described below have potential to help fund the protection of existing and planned development, promote resilient development that can accommodate flooding, shift new development away from floodplains, address the needs of vulnerable populations, and preserve open space and public benefits.

- **Flood Zone Mapping, Codes and Ordinances.** Local governments rely on flood zones mapped by the Federal Emergency Management Agency (FEMA). FEMA currently bases flood risk analysis on past events, but can incorporate additional risk associated with sea level rise into its maps if requested to do so by a local government. Within the 100-year floodplain, FEMA requires communities to meet its flood protection standards in order to qualify for federal flood insurance. FEMA provides the incentive of lower insurance rates to local governments through the Community Rating System, in which local governments receive higher ratings for practicing "good" floodplain management. For example, higher ratings are awarded for implementing building codes that provide flood protection and for requiring that development sites are elevated.

  BCDC's staff is currently working with partners to develop a regional sea level rise visualization tool that would enable local governments and others to see how various projected sea levels would impact their communities. While this type of visualization would not have any regulatory status, it could be used to inform long-range planning efforts.

- **Clustered Development.** One type of open space zoning that could be applied to reduce flood risk is clustered development, which only allows development in one area of a parcel. Where parcels are adjacent, sometimes development is clustered near adjacent property lines to maximize open space within a few parcels. Under this strategy, development could be allowed in flood zones, but strategically located back from the shoreline to provide space for the shoreline to move.

- **Purchase or Transfer of Development Rights.** A purchase or transfer of development rights program is usually a voluntary program in which landowners sell the development rights of their land to an intermediary, usually a nonprofit land trust or a public agency. Such programs have traditionally been used to protect farmland and scenic vistas from development, but could be applied to flood zones as well. Once the development rights are sold, the right to develop or subdivide that land is permanently relinquished. The landowner retains all other rights and responsibilities associated with the land (Gathering Waters Conservancy). Relinquishing the development rights is similar to having a conservation easement on the property. To establish the value of the development rights, the estimated sale price of the property with a conservation easement is subtracted from the current market value of the property with its development rights (Western Governors' Association 2001).

In the case of transfer of development rights program, a landowner who wishes to develop at higher density in another location can purchase rights from the intermediary organization or agency. This type of program is advantageous to local governments because it does not cost them anything, as long as there is a market for increased density. If such a program were applied to reduce development in a flood zone, the program could require that the development credits be transferred only to areas within a certain boundary but outside the flood zone.

- **Social Equity Study and Financial Assistance Programs.** As discussed in Chapter 2, additional research is necessary to develop more information on the potential impacts of sea level rise to particularly vulnerable populations, including low-income communities, persons with limited English proficiency, the elderly, children, and persons with disabilities or chronic illnesses, and to develop quantitative data on their vulnerability to future flooding. The region must work collaboratively to develop outreach and assistance programs for those most in need. Measures to include vulnerable populations in regional decision-making should be identified and implemented. Social-equity, environmental justice organizations and public agencies are already working on climate change mitigation and other measures to reduce climate change impacts to and increase resilience of vulnerable populations. Addressing risks and impacts associated with sea level rise must be incorporated into these efforts now to allow sufficient time to successfully adapt in the future.
- **Development Conditions.** Local governments can consider imposing special conditions when issuing permits for development of individual parcels or subdivisions that they have determined are vulnerable to sea level rise. The following examples are provided and discussed in greater detail in the Georgetown Climate Center's Sea Level Rise Adaptation Toolkit (Grannis 2011):
    - Restrictions on hard armoring—the landowner agrees not to build hard coastal armoring in the future to protect structures from flooding. These types of conditions can plan for and authorize soft-armoring solutions.
    - Removal requirements—the landowner agrees to remove structures when the tideline recedes such that his or her structure encroaches on public lands. As the seas rise, the boundary between private lands and public beaches (the tideland) will be pushed inland. This type of condition allows landowners to develop property but with the expectation that development will eventually cede to the rising seas.

    - Dedications—the landowner dedicates an easement to preserve natural buffers, floodways, or to provide public access.…
    - Impact fees—the developer is required to pay a fee to cover the costs of potential emergency response, flood-proofing infrastructure servicing the new development, future armoring, or mitigating impacts to natural resources from future armoring.
    - Flood-proofing requirements—developers must design the new development and its supporting infrastructure to be more resilient to flood impacts. For example, permits could require that roads be elevated and that sewer lines be flood-proofed.

- **Limitations on Rebuilding in High Risk Areas.** If structures in certain zoned areas are subsequently damaged by flooding, jurisdictions could limit reconstruction. The following examples are discussed in greater detail in the Georgetown Climate Center's Sea Level Rise Adaptation Toolkit (Grannis 2011):
    - Allow limited rebuilding—landowners are allowed to build smaller, more resilient structures to replace older, damaged structures; or additional setbacks could be required.
    - Totally prohibit rebuilding—landowners are prohibited from rebuilding properties destroyed when located in flood- or erosion-prone areas.
    - Allow reconstruction without armoring—landowners are allowed to rebuild properties largely as they were but with the condition that they will not build protective armoring. Regulators could then prohibit rebuilding if the structure is subsequently damaged or destroyed.

The Commission currently assists local governments in adaptation planning by providing training workshops; producing case studies featuring local examples of adaptation in action; maintaining a clearinghouse of climate change resources on the BCDC website; and working collaboratively on an adaptation planning pilot project in Alameda County, the Adapting to Rising Tides (ART) project. The Commission also works in partnership with several other agencies and organizations that provide adaptation support to local governments, such as the National Oceanic and Atmospheric Administration's Coastal Services Center, the San Francisco Bay National Estuarine Research Reserve, the Association of Bay Area Governments, ICLEI-Local Governments for Sustainability, U.S. Environmental Protection Agency's Climate Ready Estuaries program, and FEMA. Additional cooperation can help the region develop a strategy that protects the Bay ecosystem and public access to the shoreline while recognizing the key role of local governments in planning for climate change both within and beyond the Commission's jurisdiction.

Table 5.1. Summary of Adaptation Strategies

Shoreline Development
Conduct risk assessments for shoreline areas and larger shoreline projects.
Design projects to be resilient to a mid-century sea level rise projection and adaptable to longer-term impacts.
Build projects that do not negatively impact the Bay and do not increase risks to public safety, or if projects do increase flood risks, ensure that regional public benefits outweigh the increased risk of flooding.
Protect new projects from future storm activity and sea level rise by using setbacks, elevating structures, designing structures that tolerate flooding or other effective measures.
Set aside land on the upland side of levees to allow for future levee widening to support additional levee height so that no fill is placed in the Bay.
Build shoreline protection only if necessary to protect existing or appropriate planned development.
Design and construct shoreline protection to avoid blocking physical and visual public access.
Integrate shoreline protection projects with current or planned adjacent shoreline protection measures.
Include provisions for nonstructural shoreline protection methods such as marsh vegetation, whenever feasible.
Avoid, reduce or mitigate adverse impacts to natural resources and public access from new shoreline protection.
Site, design, manage and maintain public access to avoid significant adverse impacts from sea level rise and shoreline flooding.
Design any public access to remain viable in the event of future sea level rise or flooding, or provide equivalent access to be provided nearby.

Bay Ecosystem
Preserve and enhance habitat in undeveloped areas that are both vulnerable to future flooding and have current or potential value for important species.
Include a buffer, where feasible, between shoreline development and habitats to protect wildlife and provide space for marsh migration as sea level rises.
Design shoreline protection projects to include provisions for establishing marsh and transitional upland vegetation as part of the protective structure, wherever feasible.
Conduct comprehensive Bay sediment research and monitoring to understand sediment processes necessary to sustain and restore wetlands.
Update regional habitat conservation and restoration targets to achieve a Bay ecosystem resilient to climate change and sea level rise.

Governance
Develop a regional strategy for conservation and development of the Bay and its shoreline that incorporates adaptive management.
Ensure that the strategy is consistent with the climate change mitigation goals of SB 375 and the principles of the California Climate Adaptation Strategy.
Update the strategy regularly to reflect changing conditions and scientific information.
Include maps of shoreline areas that are vulnerable to flooding based on projections of future sea level rise and shoreline flooding.
Prepare the maps under the direction of a qualified engineer and regularly update them in consultation with government agencies with authority over flood protection.
Identify and encourage the development of long-term regional flood protection strategies that may be beyond the fiscal resources of individual local agencies.
Address environmental justice and social equity issues.
Integrate hazard mitigation and emergency preparedness planning with adaptation planning.
Develop a framework for integrating the adaptation responses of multiple government agencies.
Provide information, tools, and financial resources to help local governments integrate regional climate change adaptation planning into local community design processes.

Summary of Proposed Bay Plan Amendment

Adaptation to climate change should be incorporated into the Bay Plan in the following manner:

1. Create a climate change policy section of the Bay Plan that addresses the following:
    a. Incorporating sea level rise projection ranges in project design and planning and using them in the permitting process;
    b. Developing a long-term strategy to address sea level rise and storm activity and other Bay-related impacts of climate change in a way that protects the shoreline and the Bay and allows for appropriate, well-planned development that responds to the impacts of climate change and future sea level rise;
    c. Working with the Joint Policy Committee (JPC) and other agencies to integrate mitigation and adaptation strategies at a regional scale, to coordinate the adaptation responses of multiple government agencies, to analyze and address equity issues, and to support research that provides useful climate change information and tools;
    d. Providing recommendations and requirements to guide planning and permitting of development in areas vulnerable to sea level rise; and
    e. Including policies that promote wetland protection, creation, enhancement and migration.
2. Amend findings and policies on tidal marshes and tidal flats to ensure that buffer zones are incorporated into restoration projects where feasible and sediment issues related to sustaining tidal marshes are addressed.
3. Amend the policies on safety of fills by updating the findings and policies on sea level rise and moving some to the new climate change section of the Bay Plan.
4. Amend the policies on protection of the shoreline to address protection from future flooding.
5. Amend findings and policies on public access to provide public access that is sited, designed and managed to avoid significant adverse impacts from sea level rise and ensures long-term maintenance of public access areas through site-specific adaptive management strategies.

Conclusion

Global climate change has been described as one of the most challenging problems ever faced by humans. The quality of the lives of future generations depends on how the current generation deals with this challenge. The course outlined in this report is an initial, cautious and modest step in the long journey the people of the Bay Area will need to take to ensure that our region remains viable, sustainable and prosperous in the future and that our beloved San Francisco Bay continues to be protected.

APPENDIX A
METHODS FOR DEVELOPING DATA

In order to perform the analysis and mapping performed in this report it was necessary to accurately identify areas vulnerable to projected sea level rise. A team led by Noah Knowles, USGS, built a hydrodyamic model to identify areas at risk of inundation under a variety of sea level rise scenarios. In order to identify areas vulnerable to these inundation scenarios it was necessary to assemble the best available elevation data into a regional grid, integrate historic (1996-2007) tidal data and overlay with estimated increases in sea level, 40 and 140 cm.

A regional digital elevation data set was assembled that was comprised of a number of data sources, including LiDAR (Light Detection and Ranging) in the South Bay and in portions of Solano County and Napa County. Additional photogrammetry and satellite based data was assembled to create the regional data set. The data has a horizontal resolution of 2 m and nearly all areas have a vertical accuracy of between 10 and 30 cm.

In order to integrate the elevation of the water within the estuary, a hydrodynamic model of the system was driven by hourly data collected between 1996-2007 at the Golden Gate. This historic data captures the temporal range in tides as well as storm based inputs such as storm surge. The model then propagates the fluctuations throughout the Bay and towards the Delta as far east as Mallard Island. The model was verified using tide gauge data in various locations throughout the Bay. Based on the historic data, the mean monthly high water was mapped for the Bay at 200 m resolution, which corresponds with present day average monthly high water. Finally, the water surface height within the model was modified by 40 cm and 140 cm to integrate Rahmstorf's projections (2007). Further verification was performed by comparing water height fields for present day and projected conditions to land elevations (Knowles 2008).

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